

**ESTABLISHMENT OF QUALITY, RELIABILITY AND DESIGN STANDARDS
FOR
LOW, MEDIUM AND HIGH POWER MICROWAVE HYBRID MICROCIRCUITS**

Prepared by

Eugene A. Robinson

Texas Instruments Incorporated
Equipment Group
P.O. Box 6015
Dallas, Texas 75222

FINAL REPORT
Contract Number NAS8-25616

FEBRUARY 1973

NASA-CR-124211) ESTABLISHMENT OF QUALITY,
RELIABILITY AND DESIGN STANDARDS FOR LOW,
MEDIUM, AND HIGH POWER MICROWAVE HYBRID
MICROCIRCUITS Final (Texas Instruments,
Inc.) 145 p HC

N73-22419

Unclas

CSCL 14D

G3/15 17583

for
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Reproduced by
**NATIONAL TECHNICAL
INFORMATION SERVICE**
US Department of Commerce
Springfield, VA. 22151

PRICES SUBJECT TO CHANGE

152

**ESTABLISHMENT OF QUALITY, RELIABILITY AND DESIGN STANDARDS
FOR LOW, MEDIUM, AND HIGH POWER MICROWAVE HYBRID MICROCIRCUITS**

By

**TEXAS INSTRUMENTS INCORPORATED
EQUIPMENT GROUP
ADVANCED DEVELOPMENT BRANCH
P.O. Box 6015
Dallas, Texas 75222**

**FINAL REPORT
CONTRACT NUMBER NAS8-25616**

FEBRUARY 1973

for
**National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812**

**The International System of Measurements
was used in this report.**

**This work was administered under the technical
direction of the Quality and Reliability Assurance
Laboratory of the George C. Marshall Space Flight
Center.**

TABLE OF CONTENTS

<i>Section</i>	<i>Title</i>	<i>Page</i>
I	INTRODUCTION	1
II	DESIGN AREA STUDIES	2
	A. Introduction	2
	B. Processes	2
	C. Substrates	4
	D. Conductors	7
	E. Semiconductor Devices	9
	F. Resistors	18
	G. Inductors	19
	H. Capacitors	20
	I. Packaging	21
III	LIFE TEST AND FAILURE MODES OF MICROWAVE COMPONENTS AND CIRCUITS	22
	A. Introduction	22
	B. Microwave Semiconductor	22
	C. Microwave Capacitors	23
	D. Microwave Receiver Test	25
	E. Integrated Solid State Transceiver	26
	F. Summary	32
	Appendix	
	A Bibliography Notes	
	B Quality, Reliability and Design Standards for Microwave Hybrid Microcircuits	
	C MSFC Standard 85M03926 Revisions and Additions	
	D Thin-Film Capacitor Burn-in Data	

LIST OF ILLUSTRATIONS

<i>Figure</i>	<i>Title</i>	<i>Page</i>
1	Thermocompression Bonding Chisel	11
2	Typical Microwave Transistor Geometry	14
3	Microwave Capacitor Structure	20
4	Microwave Receiver Circuit	26
5	Microwave Hybrid Microcircuit Electrical Schematic	27
6	ISST Module	29
7	Module Transmitter	31
8	Module Receiver	31
9	ISST Module Screening Flow Chart	32

LIST OF TABLES

<i>Table</i>		<i>Page</i>
I	Substrate Properties	5
II	Visual Inspection Criteria	15
III	Microwave Component and Hybrid Microcircuit Life Test	22
IV	High-Temperature and High-Voltage Monolithic Tantalum Capacitor Life Test	24
V	X-Band Receiver 125°C Burn-in Data	28
VI	ISST Components	30

ABSTRACT

Quality, reliability, and design standards for microwave hybrid microcircuits were established. The MSFC Standard 85M03926 for hybrid microcircuits was reviewed and modifications were generated for use with microwave hybrid microcircuits. The results for reliability tests of microwave thin-film capacitors, transistors and microwave circuits are presented. Twenty-two microwave receivers were tested for 13,500 unit hours. The result of 111,121 module burn-in and operating hours for an integrated solid-state transceiver (ISST) module is reported.

SECTION I

INTRODUCTION

The work performed by Texas Instruments to originate quality, reliability and design standards for microwave hybrid microcircuits is described in this report. The work was done under Contract Number NAS 8-25616 for the George C. Marshall Space Flight Center (MSFC) of the National Aeronautics and Space Flight Administration.

The program objectives were to originate a standard that establishes the necessary controls for the design and fabrication of microwave hybrid microcircuits for space applications, review MSFC Standard 85M03926 and provide revisions and/or additions with justification, and to obtain reliability test data on microwave hybrid components and microcircuits.

Design area studies on microwave hybrid microcircuit processes, substrates, components and packaging are presented in Section II. Life test and failure modes of microwave components and circuits are detailed in Section III. The appendixes include the Bibliography Notes; the Quality, Reliability and Design Standards for Microwave Hybrid Microcircuits; the additions and revisions to MSFC Standard 85M03926; and Thin-Film Capacitor Burn-In Data.

SECTION II

DESIGN AREA STUDIES

A. Introduction

The program to gather information for use in preparing a set of standards and controls for the design and fabrication of microwave hybrid microcircuits was completed. The information was collected from all available sources, including technical publications, conference reports, individual contracts, correspondence, and from Texas Instruments experience in the development and production of microwave integrated circuitry. Selected bibliography notes are included as Appendix A.

The areas of investigation included MSFC Standards 85M03926 and 85M03927, recent technological developments, and specific microwave hybrid microcircuit requirements.

The results of the studies concerning the design, processing, assembly and evaluation of microwave hybrid microcircuits are presented in this report.

B. Processes

A major factor to be considered in fabrication techniques used to build hybrid microcircuits is the choice of processes, thick or thin film. A survey of the important considerations and principal features of each process is presented in this subsection. Detailed characteristics and relative advantages are given in subsequent sections.

1. **Thick Film**—The thick-film process has been associated with an emphasis on low-cost, high-volume applications. In general, the production quantities must be substantial to realize the full economic impact.

Conductor, resistor, and/or capacitor patterns are formed on a dielectric substrate and the materials are fired, usually in the order listed, under controlled multizone-furnace conditions of temperature, time and atmosphere. The screening pastes are mixtures of conductor, resistor or dielectric materials, with a glass frit base which serves as a binder for forming the component pattern on the substrate. In practically all instances, the resistors are adjusted to the design value using laser or air-abrasive trimming methods. The process is relatively simple, usually employs low-cost substrate materials and, in many applications, an individual substrate does not represent an extremely complex electronic function.

Pattern definition can normally be controlled to dimensions of a few thousandths of an inch. Typical patterns, using a 3-25 mesh stainless steel screen in production, are 0.005-inch lines on 0.010-inch centers.¹ Using a 0.002-inch metal mask under laboratory conditions, it is possible to form 0.002-inch lines on 0.004-inch centers.¹ For critical applications such as constant impedance transmission lines, it is necessary to delineate the final pattern by photoetch methods. Resistivity of the higher conductivity fired gold pastes is 2 to 4 times higher than that of the bulk material. Fired silver pastes have substantially lower resistivity (approximately that of bulk gold), but should be overplated with gold to form a surface suitable for semiconductor

mounting and bonding operations. The glass frit base which serves as a binder also produces high losses in high-frequency circuits. Thus, thick film is generally not suitable for microwave circuit patterns.

Resistors formed by the thick-film process have some minor disadvantages in microwave circuits from the design and performance viewpoints, particularly at higher frequencies. The dimensions are usually greater than those for a corresponding thin-film resistor (except where power dissipation is the controlling factor) and, thus, the departure from the characteristics of a discrete component is exaggerated. The variation in geometry, caused by the adjustment pattern, results in unpredictable rf discontinuities.

Thick-film capacitors are not in general use in microwave circuits. The combination of low loss, small dimensions and close tolerances are difficult to achieve when using thick-film techniques.

2. Thin Film—The thin-film process is generally characterized by formation of precision components on more expensive base materials and relatively higher production costs.

Materials are deposited in controlled-atmosphere chambers by use by filament evaporation, electron-beam evaporation, sputtering and pyrolytic deposition. Patterns are formed by photomasking and etching techniques. Materials can be selectively deposited by using photoplatting methods. Dielectric layers can be formed from anodic materials by using electrolytic anodization. The layers may also be deposited through evaporation, reactive sputtering and pyrolytic anodization. The process is relatively complex and the substrate materials usually are more costly; for example, high-purity alumina and beryllia ceramics, sapphire and silicon. A thin-film network substrate normally comprises a relatively complex circuit with a large number (10 to 50) of active and passive components.

Pattern definition can normally be controlled to dimensions of a few ten-thousandths of an inch. The width of a typical conductor which has been plated to 0.0002-inch thickness can be held within 0.0002-inch. The conductivity of the plated gold is normally 85 to 90 percent of the bulk material. Plated silver lines have somewhat better conductivity, but should be overplated with gold to permit alloying and bonding. The thin layer of interface material such as chromium, deposited to improve adhesion, does not measurably affect the microwave conductor properties.

Resistors formed by deposition and photoetching can be dimensionally controlled to about 0.0001-inch to 0.0002-inch width with slightly greater variations in length. Resistor values can be controlled to better than 5 percent through the use of anodic trimming, and without trimming. Film resistivity does not change significantly with frequency and, since the resistor geometry is fixed, electrical discontinuities may be design-compensated.

Thin-film capacitors are relatively small, particularly when tantalum oxide is the dielectric material. It is difficult to maintain precise tolerances (within 5 percent), especially in the low-value picofarad range (<10 pF) when using high dielectric constant materials such as titanium oxide and tantalum oxide. The reliability of microwave thin-film capacitors under conditions of high-voltage, high-temperature stressing is marginal based on tests conducted to date.

C. Substrates

The selection of substrate materials for use in fabricating microwave hybrid microcircuits involves the following factors:

1. Dielectric constant
2. Dielectric loss
3. Surface finish
4. Dimensional tolerances
5. Composition (purity)
6. Magnetic properties
7. Thermal conductivity
8. Thermal expansion
9. Uniformity
10. Electrical conductivity
11. Availability and economics.

The ways in which these factors determine the choice of substrate materials are described below. In most instances, there are mutually incompatible aspects which do not allow an optimum selection in all respects and which require that some compromise be made in the selection of suitable substrate materials.

1. **Dielectric Constant**—The dielectric constant of commonly used microwave substrate materials varies from 3.78 for fused quartz (SiO_2)¹ to 9.5 for 99.5 percent alumina and sapphire to approximately 100 for rutile (TiO_2).² In microwave circuitry, the principal function of the dielectric substrate is to serve as a base for fabricating transmission lines (usually microstrip) used as distributed elements and interconnections, and for forming thin-film inductors. Properties of common substrate materials are shown in Table I.

The effect of a dielectric-constant of low value is to increase the circuit dimensions and the amount of power radiated from the transmission lines. The effect of dielectric constant of high value is to increase the stray capacitance of inductors and to emphasize the effect of dimensional tolerances on circuit design and performance. A dielectric constant of about 10 has been found to give an optimum compromise for design purposes in the majority of cases. This is one of the reasons for the wide-spread use of high-purity Al_2O_3 ceramics and sapphire in microwave hybrid integrated circuits.

2. **Dielectric Loss**—Dielectric loss is determined by material characteristics and purity. Quartz (fused silica), high-alumina (99.5 percent) ceramics, sapphire, and rutile (when considered on a wavelength basis), have satisfactory loss characteristics for use as microwave microstrip substrate materials. Glass, glazed alumina ceramics and beryllia are poor microstrip substrate materials because of their relatively higher loss factor, that is, approximately two orders of magnitude greater than those listed above.¹ The conductor loss is the dominant factor when high-purity quartz, alumina ceramics, and sapphire are utilized in microwave circuits.

TABLE I. SUBSTRATE PROPERTIES

Material	ϵ_r (10 GHz)	$\tan \delta$ (10 GHz)	K	Other Properties
99.5% Al_2O_3 Ceramic	9.7	0.0001	0.075	Poor surface for thin-film components, wide range of sizes and shapes possible, low cost
99.5% BeO Ceramic	6.4	0.0003	0.43	
96% Al_2O_3 Ceramic, glazed	7.2*	0.008*	0.002*	Good surface, low cost
Fused Quartz	3.78	0.0001	0.014–0.023	Excellent surface possible
TiO_2 Ceramic	~90	0.0015	0.01 typ	Poor surface
Sapphire	9.3–11.7	0.0001	0.09	Good surface
SIC	6.7	—	0.2–0.8	Very hard
Ferrites	12–16	0.001 typ	0.06 typ	Nonreciprocal propagation possible
1000 Ω -cm Silicon	11.8	~0.015 eff.	0.25	Excellent surface possible, semiconductor devices can be fabricated insitu
Semi-insulating GaAs	11.1	—	0.095	

* Glaze only

K = thermal conductivity in gram cal/sec/cm²/°C/cm

To convert to watts-cm/cm²-°C, multiply by 4.18

3. **Surface Finish**—Surface finish has a significant effect on loss for microstrip transmission lines. Tests to compare ground and polished surfaces and as-fired and lapped surfaces³ have been made. It is apparent that a finish of 10 microinches, or better, is satisfactory for fabricating high-Q (low-loss) microstrip lines, although a 2- to 4-microinch finish could provide some improvement. An extremely high-quality surface finish of 1 microinch, or better, is required for thin-film capacitor substrates and the uniformity and reliability of thin-film resistors is considerably enhanced by the use of substrate materials with a comparable finish. The requirements of low microstrip transmission line loss and 1-microinch surface finish for thin-film components can be satisfied by using selectively glazed, high-purity alumina ceramics⁴ or polished sapphire⁵ for substrate materials.⁶

4. **Dimensional Tolerances**—High-purity alumina substrates having dimensions on the order of 2- by 2- by 0.020-inch thick can be procured with dimensional tolerances of ± 0.004 inch per inch of camber with a surface finish of 10 microinches in production quantities at nominal cost. These tolerances are satisfactory for most microwave circuit applications. Closer tolerances can be obtained by grinding and polishing or special processing at a cost premium of about an order of magnitude higher. Materials such as sapphire and fused silica require grinding and polishing and they have a higher intrinsic material cost. In general, the use of higher substrate costs can be justified only in high-density circuit packaging and/or where there is a need for close dimensional tolerances or a specific substrate material. The use of ferrite ceramic substrates is an example of the latter requirement.

5. **Thermal Expansion**—The thermal coefficient of expansion must be considered for metalization systems, component mounting, and for individual circuit substrate mounting on carrier plates or packages. The thermal expansion coefficient for beryllia and alumina in the high-purity form is about 6×10^{-6} . Metals which have approximately the same coefficient are chromium, iridium, molybdenum, niobium, silver, tantalum and vanadium.

6. **Uniformity**—The effective dielectric constant is a key factor in the design and fabrication of microwave microstrip transmission lines. It has been determined that the effective dielectric constant of high-purity alumina substrates varies between suppliers and as much as 10 percent between batches from the same supplier.³ To fabricate microwave integrated circuits having reproducible electrical performance, it is essential that the dielectric constant of the substrate material be carefully monitored and controlled.

7. **Electrical Conductivity**—Normally, the volume resistivity of most dielectric substrate materials is not a critical factor in microwave hybrid circuit performance and reliability. However, the volume resistivity of silicon and, to a lesser degree, ferrites must be included as a design factor. Since the high-frequency loss factor is a very sensitive indicator, the control of this parameter is sufficient to eliminate the effects of a low-resistivity material.

8. **Composition (Purity)**—Evaluation tests show that alumina ceramic substrates of 99.5 percent purity are satisfactory for use in microwave integrated circuits.³ Other materials which have loss factors in the range of 10^{-4} at microwave frequencies are clear fused silica and sapphire. It is desirable to verify the loss factor, or effective Q, by measurements similar to those described by Lemke.³

9. **Magnetic Properties**—Integrated microwave systems, in general, require the use of ferrite elements for phase shifters, circulators, and filters. Consequently, ferrite ceramic materials are employed in their fabrication. Nonmagnetic ferrites, that is, ferrites with a Curie temperature much below room temperature, can be sintered together with magnetic ferrites to form smooth “nonmagnetic” substrates with magnetically active zones.⁷ Electrical discontinuities are low due to the similar natures of the materials and the ferrites can be machined and polished more easily than alumina to obtain low-loss transmission lines. Tightly coupled broadband transitions can be made between the ferrite and alumina substrates where required. The only disadvantage of ferrites as compared to alumina is the 10-times lower thermal conductivity.

10. **Thermal Conductivity**—The thermal conductivity of common substrate materials ranges from 0.003 for clear fused silica to 0.088 for high-purity alumina ceramic and sapphire to 0.55 for 99.5 percent beryllia ceramic.* This factor must be considered in conjunction with the electrical and mechanical requirements when selecting the substrate material for a specific application. High-purity alumina substrates are most commonly used for microstrip transmission lines while beryllia substrates are employed as carriers for microwave power transistors and similar applications.

11. **Availability and Economics**—Of the several materials used for microcircuit substrates, high-purity alumina is available in the widest range of dimensions at a reasonable cost. High-resistivity silicon is limited in the range of dimensions available and/or are available only at a cost premium relative to the materials listed above. Geometry requirements, circuit

*Units are gram cal/sec/cm²/°C/cm.

performance aspects and the substrate cost relative to that of the total circuit must be evaluated in the course of specifying substrate materials for microwave hybrid microcircuits.

D. Conductors

The materials and/or processes used in fabricating conductors for microwave transmission lines and distributed circuit elements should fulfill the following requirements.

Compatibility with other circuit fabrication material and processes

Suitability as a base for alloying, bonding, and welding assembly operations

Adherent to substrate and/or other interface materials

Specific resistivity should be less than 10×10^{-10} ohm-cm

Allow formation of conductors at least 2 to 3 skin depths in thickness

Possess capability for forming conductors of about 0.0002-inch width tolerances

Resistant to electrochemical corrosion and current-induced electron migration.

No single material possesses the ideal characteristics for use as a microwave conductor. Copper, silver, aluminum, and gold materials have been considered as the major constituent of an rf conductor. A number of other metals are used in conjunction with these materials to provide substrate adherence. Consideration is required for chemical, electrolytic and diffusion barriers, thermal expansions compatibility, and suitable bonding surfaces. These materials include chromium, cobalt, hafnium, molybdenum, nickel, niobium, palladium, platinum, rhenium, tantalum, titanium, tungsten and zirconium.

1. **Process Capability**—Gold and silver can be deposited by thin- or thick-film techniques. Aluminum is invariably placed on a substrate by vacuum deposition processing. Copper, gold and silver can be deposited initially, and/or the material thickness can be increased to a suitable value by plating operations. Aluminum must be formed to the desired thickness in the vacuum deposition operation.

2. **Assembly Base**—Gold is considered to be the most suitable material as a base for alloying, bonding and welding operations because of its corrosion resistance and desirable bonding properties. It readily forms an alloy with semiconductor materials, and leads can be attached using thermocompression bonding or split-tip welding equipment. Copper and silver are usually covered with a layer of evaporated or plated gold when these two materials are used as film conductors. Aluminum and gold leads can be attached to aluminum-film conductors by thermocompression or ultrasonic bonding methods. However, it is very difficult to perform alloying operations on aluminum conductor pads. At present, aluminum is used primarily in applications where extreme radiation tolerance is desired.

3. **Substrate Adherence**—Evaporated or sputtered aluminum adheres well to most substrate materials. The adherence of copper, silver and gold, in particular, to the substrate is usually enhanced by utilizing a more adherent interface material between the conductor and the substrate. Chromium, molybdenum, nickel, tantalum, titanium and tungsten are some of the more common interface materials used to improve the conductor-substrate bond.

Thick-film conductor pastes depend to a large extent on the glass content in a substrate material for adherence. Since the ceramic substrate materials used in microwave circuits

have a high alumina content, adherence is usually enhanced by using a rough substrate surface. Since a smooth surface is required to minimize electrical losses at microwave frequencies, deposited conductor films are preferred for use in microwave circuit applications.⁸

4. Specific Resistivity—All of the common conductor materials (such as aluminum, copper, gold and silver) have specific resistivities much less than 10×10^{-5} ohm cm. Since the interface materials are deposited in thicknesses of only a few hundred angstroms, the associated conductor losses are negligible.⁸

5. Conductor Thickness—To minimize the resistive loss in rf transmission lines, the conductor thickness should be several skin depths. At 10^9 Hz, the skin depth for plated gold is approximately 2.5 microns (100 microinches); therefore, the conductor thickness for microwave transmission lines should be a minimum of several hundred microinches. Skin depth varies inversely with the square root of frequency and directly as the square root of resistivity; thus, the required conductor thickness decreases with frequency. The skin depth for copper and silver is somewhat less than that for gold, while the skin depth for aluminum is slightly greater.

Transmission lines formed from copper, gold and silver by thick-film methods can be electroplated to the desired thickness, starting from a thin layer of deposited material. Material for aluminum conductors is vacuum-deposited to the required thickness. Thick-film conductors with gold or silver bases can be screened and fired by conventional processing methods.

6. Conductor Width—Conductors used for microwave transmission lines must have dimensional tolerances less than 0.001 inch for optimum performance. Even closer tolerances (approximately 0.0002 inch) are required for the spacing of conductors used for microwave power couplers. This dimensional control can be achieved by the use of photomask etching methods.

Selective plating through a photomask gives a pattern definition equal to or better than photoetching. This method conserves the use of costly materials, such as gold, since there is little or no material lost in the deposition and pattern-forming process.

In general, ground planes are required for microwave stripline circuits and electrical grounding is needed at specific points on the circuit pattern. Ground connections can be made by drilling holes in the substrate before the conductor-forming operations and by plating through these holes when the conductor patterns and ground plane are formed.

7. Corrosion and Migration Resistance—Resistance to electrochemical corrosion and current-induced electron migration is of significance, particularly when closely spaced patterns or thin-film components such as capacitors are involved. Aluminum and silver conductor films are susceptible to electron migration unless suitable barriers are imposed during circuit processing. Molybdenum and chromium are subject to electrochemical corrosion in the presence of moisture and an applied voltage. The results of a series of tests indicated that Ti-Pt-Au, W-Au, Ni-Au and Ta-Au gave superior results as metalization systems.

8. Crossovers—Crossover use should be minimized in microwave circuit design. Suitable crossovers can be implemented with wire or ribbon jumpers and can be fabricated with stamped or chemical-etch techniques.

9. **Summary**—Thin-film conductors for microwave circuits are usually formed from gold with a thin layer of suitable interface material to provide substrate adherence. Conductor patterns, ground planes, and ground conductors are formed by selectively electroplating through a photoresist mask over a thin layer of vacuum-deposited material. Conductors can be formed using thick gold or silver films, but it is generally necessary to define patterns precisely, using photoetching methods.

E. Microwave Semiconductor Devices

Microwave semiconductor devices are more complex than low-frequency semiconductors. A number of factors must be considered to control the performance and reliability of the devices. Major consideration should be given to the listed areas for reliable microwave devices.

1. Chip geometry and metalization
2. Mounting techniques
3. Bonding methods and controls
4. Packaging
5. Thermal characteristics
6. Visual inspection criteria.

1. **Chip Geometry and Metalization**—The geometry and metalization of a microwave transistor is vital to device performance and reliability. The geometry normally consists of interdigitated metalization patterns that have widths of 1 micron or less. The device may use mesh, overlay, or interdigitated structures to maximize the emitter periphery-to-base area. Very shallow emitter diffusions are used to minimize emitter-base junction debiasing and base-widening effects. The proper geometry will minimize hot spots and promote an even temperature profile across the chip.

The metalization on a semiconductor device must have a number of properties.

Mechanical adherence

Good electrical contact

Compatibility with alloying and bonding operations

Capability of high current densities and high-temperature operations.

The deficiencies of aluminum with high temperature and high current densities and its comparison with gold are well documented.⁹ Gold is an excellent material with respect to operation at the high current densities prevalent with microwave semiconductor devices. The use of interface materials between silicon and gold provides the necessary adherence and electrical properties. A typical system with good reliability is a platinum silicide-titanium-tungsten-gold metal system. The pattern definition is accomplished with a photomask process and selective etching and/or plating. The back side metalization is usually sintered gold which provides a low ohmic contact and an excellent material for alloying operations.

An example of microwave transistor design and metalization effects on device reliability can be seen in the results of a recent accelerated life test.¹⁰ Three tests were run at different current densities and junction temperatures on a 5-watt, 2-GHz transistor. The basic

transistor was an interdigitated transistor with 100 emitter fingers and 102 base fingers. The emitter fingers were connected in groups of 5, with interconnecting metalization. Each two groups of emitter fingers were then connected to an emitter bond pad by means of separate metal conductors. In each test lot, transistors with aluminum and gold metalization were tested. The devices were run at three different junction temperatures (160°C, 210°C, and 230°C) and at three different current densities ($J = 2 \times 10^6$, $J = 1 \times 10^6$, and $J = 0.8 \times 10^6$ ampere/cm²) so that the calculated MTF for the aluminum devices was 30 hours. In the low-temperature, high-current and high-temperature, low-current test, the aluminum-metalized transistors failed in 3 to 7 hours. The gold-metalized transistors failed in a 50- to 1,000-hour time span. In general, the gold metalization provided a 10:1 life improvement. The test indicated a problem in device geometry in that the metalization connecting the emitters to the emitter bond pads had a severe thermal gradient and became open-circuited due to electromigration.

As a result of the first test, which indicated poor transistor geometry, another test was run. The second test compared the original aluminum interdigitated transistor with a glass-passivated aluminum transistor with a mesh structure. The junction temperatures were set at 210°C and approximately 0.4×10^6 ampere/cm², current density. The calculated MTF was 250 hours for the interdigitated transistor and 700 hours for the glass-passivated mesh structure. The interdigitated transistors failed in the 160- to 250-hour time span. The mesh transistors with glass passivation were still operating without failure after 8,500 accumulated operating hours.

In general, gold metalization indicates that an improvement in operating life can be obtained, but that a well-designed, glass-passivated, aluminum metalization transistor may also have a high MTF.

2. Mounting Techniques—The microwave semiconductor device mounting method can have a marked effect on device performance and reliability. Thermal impedance from the chip to the heatsink should be minimized by mounting with materials of high thermal conductivity and by having the minimum number of interfaces. The best method for mounting silicon chips is through the use of a gold-silicon eutectic alloy. Other mounting methods, such as the use of high-temperature solders (gold-tin, gold-germanium and gold-silicon), and low-temperature solders (lead-tin and indium-tin) or epoxy materials, are much less satisfactory from the standpoint of electrical characteristics, mechanical strength, durability and/or thermal conductivity. Particular care should be taken to eliminate voids between mounting surfaces. Voids can be detected by the use of X-ray techniques or by noting anomalies in the thermal-impedance measurements.

3. Bonding Methods and Controls—The semiconductor device may be connected by thermocompression ball or chisel (wedge) bonding, ultrasonic bonding, brazing and/or parallel-gap welding. Thermocompression ball bonding is a generally accepted method for lead attachment to semiconductor chips. When made under the proper conditions, thermocompression ball bonding is extremely reliable. Several conditions must be satisfied.

Chip and capillary temperatures must be optimized and closely controlled for the specific bonding operation.

Capillary force must be properly set and controlled.

Visual inspection and bond-strength test must be conducted at specified intervals for adequate quality control.

In many instances, it is necessary to use chisel bonding when extremely small bond wires (0.0003 to 0.0005 inch) are used where small (typically 0.001-inch square) bonding areas

exist on the semiconductor device. Bonding tests should be conducted to determine the proper bonding conditions for each expected bonding situation. Chisel temperature, substrate temperature, chisel configuration, bonding force, and dwell time must be controlled to produce reliable bonds. These are listed in the order of their relative importance.

Tests have shown that bonds formed at higher substrate temperatures (150° to 250°C) were superior. Round-edge chisels were far superior to sharp-edge chisels, and heavy bonding forces tended to increase wire breakage. During the test, it was noted that optimum bonds resulted with a bond-width to wire-diameter ratio of approximately 2:1.

The proper chisel shape and dimensions which have given excellent results with 0.0003-, 0.0005- and 0.0007-inch gold wire are illustrated in Figure 1. It should be noted that chisel pressure must be varied according to bonding wire diameter. It is essential that bonding parameters be continuously monitored and that frequent bond-pull tests be run to obtain consistent results.

Beam-lead devices with 0.005- by 0.005-inch leads, or smaller, are normally attached with thermocompression bonding techniques. Beam-lead units with larger leads can be attached with parallel gap-welding techniques.

Ultrasonic bonding can be used with microwave semiconductor devices. This technique is particularly applicable for bonding aluminum wires to aluminum bond pads, found usually in circuits designed for maximum resistance to radiation effects.

Device leads may be bonded using solder reflow methods. Heat is usually applied with a jet of heated inert gas, or by the use of parallel gap-welding equipment.

All of these bonding techniques can give excellent results. It is essential that suitable bonding equipment for the operation be used, along with the proper monitoring controls for reliable bonds. The controls should include equipment setup, calibration, periodic maintenance and sample lead-pull tests on a lot or shift basis.

4. Packaging—Microwave semiconductor devices are packaged in numerous configurations including chips, carrier-mounted chips, beam-lead chips, and hermetic packages.

The use of chip devices in microwave circuits provides better electrical characteristics than those characteristics provided by package devices, since package parasitics are eliminated.

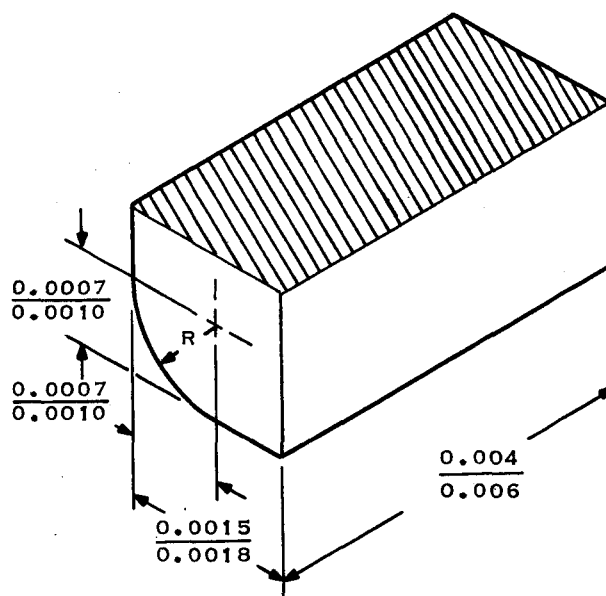


Figure 1. Thermocompression Bonding Chisel

The major disadvantage is the difficult, if not impossible, task of performing high-frequency electrical tests on the chip. Another disadvantage is that there is little or no protection for the chip when it is directly attached to the circuit substrate.

Carrier-mounted chips have the advantages of allowing testing before circuit mounting, while parasitic lead inductance is minimized. A degree of mechanical protection can be given to the chip with a properly designed carrier. Good thermal characteristics can be obtained if the carrier uses beryllia as a substrate material.

Beam-lead chips offer the lowest lead inductance possible and can be rf-tested before circuit assembly. Since beam-lead chip devices have a minimum number of interconnections for circuit assembly, manufacturing assembly cost can be reduced and circuit reliability increased.

All of these types of packaging require that the chip junction areas be passivated unless the circuit assembly is accomplished in a controlled environment with carefully controlled assembly processes. Past experience indicates that silicon-nitride passivation is superior to silicon oxide.

Hermetically sealed semiconductor devices offer convenience in device testing along with ease of assembly and replacement. They are more rugged and are suited to assembly by personnel untrained in alloying and bonding operations. In general, electrical performance obtained is lower than that obtained with other device packaging techniques; additional circuit-design difficulties are introduced with the additional package parasitics.

5. Thermal Characteristics—Nearly all of the failure modes associated with high-frequency silicon transistors are induced or accelerated by high operating temperatures.^{9,11} The main failure modes propagated by high junction temperatures in microwave transistors is metalization electromigration and secondary breakdown. Because of the correlation between junction temperatures and failure rate, it is essential that a semiconductor device be completely characterized with respect to its thermal impedance under the conditions of actual operation. To attain the necessary control of the maximum junction temperature, two things must be resolved. These are the method of determining peak junction temperature, and defects characterization which can result in excessive junction heating.

There are two general techniques for measuring semiconductor device junction temperature. One measurement technique is the method by which junction temperature is related to base-emitter voltage under uniform device temperatures. Power is then applied to the device and the base-emitter voltage is sampled during a small fraction of the duty cycle. In this way, the junction temperature can be measured as a function of power dissipation. The thermal impedance, θ_{jc} is defined as the difference between the junction temperature and the reference temperature (usually the heatsink or module case temperature) per watts dissipated power, that is, °C/watt. For relatively sample devices with a small junction area, this method provides a sufficiently accurate indication of the maximum junction temperature. However, for high-power microwave devices which may have several hundred elements covering an area up to 300 square mils, measurements by this technique will give results which are average values and which may be substantially in error for peak measurements.

The second means for measuring junction temperature involves the use of an IR radiometer with a resolution of about 1 mil. In principle, this instrument may be calibrated by

heating the semiconductor device on a hot plate and recording the readings over a range of temperatures. In reality, there are several effects which must be considered to obtain reasonably accurate results. However, this principal measurement error is caused by the fact that the silicon is transparent at IR frequencies and radiates energy from the subsurface portion of the device. Because of this radiated energy, the instrument does not give a true indication of the surface temperature due to the temperature valuation between the surface and the heatsink. These inaccuracies can be resolved by the use of a transistor coating material which has the following properties:

- a. High emissivity to provide a high level of radiation.
- b. High IR absorption coefficient to ensure that radiation transmitted from the lower portions of the device does not reach the detector.
- c. Low surface tension to permit the application of a thin coat.
- d. Low thermal conductivity to ensure that no additional heat paths are provided.
- e. Does not affect transistor performance.
- f. Does not dissipate rf or dc power.

Experimental data has shown that Zelon black paint, a Sherwin-Williams product, has the right properties for use as a transistor coating material. This paint has a good radiation level, low surface temperature and no observable affect on the transistor dc or rf performance.

In summary, the maximum thermal impedance of high-power microwave semiconductor devices can be measured accurately by the use of an IR radiometer with suitably coated test units. Substantial errors can be introduced in the measurement of uncoated devices.

Excessive heating of devices can generally be attributed to one of the following types of defects. A void in the alloy metalization between the transistor chip and the BeO substrate or between the BeO substrate and the metal heatsink can cause temperature differentials over 50 percent higher than normal. These voids can usually be detected by X-ray photographic examination, but in cases where the void is over substantially the total chip area, detection may be extremely difficult. This type of gross defect can usually be recognized by measurement of the junction temperature, using the base-emitter voltage method.

Excessive junction temperatures can also be caused by hotspots resulting from a poor transistor design, poor metalization contact, or defective metalization patterns. These lead to excessive localized power dissipation and, consequently, the result is higher junction temperatures in the immediate area. Unless the defect is sufficient to cause device performance degradation, it can only be recognized by the IR thermal-scanning method.

6. Electromigration—The mass transport of a metal by momentum exchange between thermally activated metal ions and conducting electrons is very likely the prime failure mechanism in microwave power transistors. The main factors in electromigration is high junction temperature, high current density in the metal and low activation energy of the metal used. The mean-time-to-failure is related to these factors by

$$MTF = \frac{Wte^{\phi/KT}}{cJ^2} \quad (1)$$

where

ϕ = activation energy of metal

c = constant

W = width of conductor in cm

t = thickness of conductor in cm

K = Boltzmann constant

T = temperature in °K

J = current density.

With proper device design, the MTF can be increased if current densities can be kept low and a metal with high activation energy is used. With proper device geometry and ballasting techniques, current and temperature gradients (hotspots) can be minimized and/or eliminated.

The choice of a gold conductor system over an aluminum metal system can extend the MTF by an order of magnitude. Junction temperature can be lowered further with good thermal and circuit design. Assurance of reliable device operation in a design should be verified by using IR scanning techniques.

7. **Visual Inspection Criteria**—The complex geometry of a typical microwave transistor is illustrated in Figure 2. The large number of narrow, closely spaced base and emitter fingers,

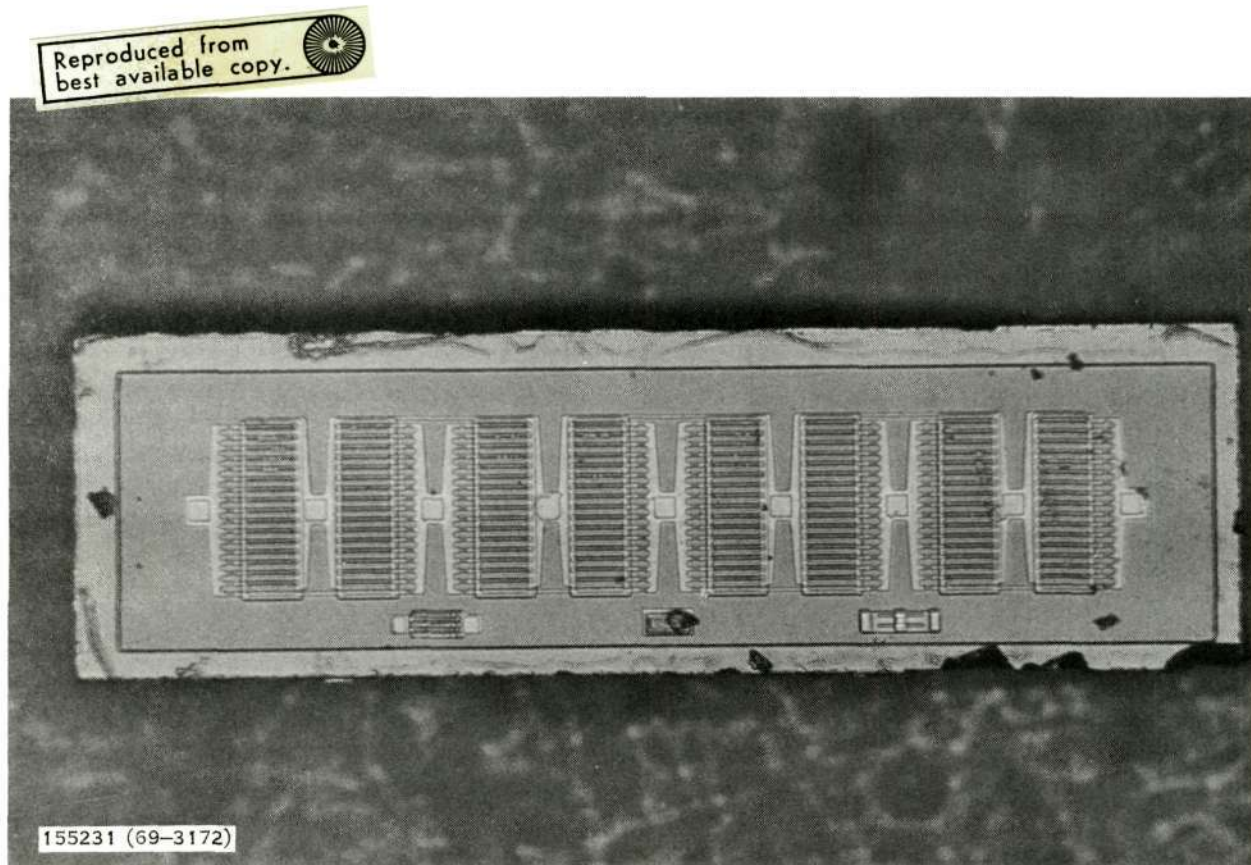


Figure 2. Typical Microwave Transistor Geometry

emitter ballasting resistors, and small bond areas can be seen in this photograph. Definite criteria must be established which define transistor die metalization, oxide, diffusion, and scribing defects along with die attachment, wire bond, and bonding wire defects. In general, microwave diodes are not as complex as microwave transistors, but the geometry and metalization patterns incorporate similar dimensional tolerances. An example of typical visual inspection criteria is shown in Table II.

TABLE II. VISUAL INSPECTION CRITERIA

1. PURPOSE

This document establishes the visual inspection criteria for a microwave transistor.

2. SCOPE

This document describes defects not acceptable for a high-quality microwave transistor. Defects such as metalization, oxide and diffusion, scribing, mounting, wire bond, bonding wire, and contamination defects are covered.

3. APPLICABLE DOCUMENTS

Unless otherwise specified the applicable documents referenced are:

MIL-STD-105 (29 April 1963)	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-883 (20 Nov 1969)	Method 2010.1, Level A, Notice 2 Test Methods and Procedures for Microelectronics

4. INSPECTION EQUIPMENT

The following equipment and apparatus are applicable to the inspection specified herein:

- (a) Binocular microscopes capable of 30 to 400 magnification power
- (b) Visual standards (gages, drawings, photographs, etc.) necessary to perform an effective inspection and enable the operator to make objective decisions as to the acceptability of the device being inspected.

5. REQUIREMENTS

The inspection specified herein shall be performed on the transistor on a 100-percent basis unless otherwise stated, to detect and eliminate transistors with defects which could lead to device failures in nominal application.

6. PROCEDURE

The transistor shall be visually inspected in a suitable sequence of observations to determine compliance to the applicable specifications.

6.1 Metalization Defects (100 X Min.)

- 6.1.1 Any scratch in the metal that leaves less than 50 percent of the original design-width metal undisturbed and exhibits oxide or silicon.
- 6.1.2 Any scratch that leaves less than 75 percent of the original design-width metal over an oxide step undisturbed and exhibits oxide and silicon.
- 6.1.3 Metalization corrosion or lack of metalization adherence, as evidenced by lifting, peeling, or blistering.
- 6.1.4 Any void or metal smear that leaves less than 75 percent of the original design-width metal undisturbed.
- 6.1.5 Any bridged metalization, either by smearing during probing or deposition, that reduces the normal distance between adjacent strips by 50 percent or greater.
- 6.1.6 (a) Any evidence of misregistration as shown by registration marks or bonding pads shall be considered as an alignment registration reject.

TABLE II. VISUAL INSPECTION CRITERIA (Continued)

- (b) Any contact window that has less than 75 percent of its area covered by metalization shall be considered as an alignment reject.
- 6.2 Oxide and Diffusion Faults (100 × Min)
 - 6.2.1 Any oxide or diffusion fault that allows budging between any two diffused areas, any two diffused areas, any two metalization stripes or any combinations thereof not intended by design.
 - 6.2.2 Crazeing or discoloration in the active area.
 - 6.2.3 An absence of oxide or fault visible at the edges or continuing under the metalization such as to cause apparent short between metal and the underlying material.
 - 6.2.4 Any active junction not covered by oxide.
 - 6.2.5 A contact cut which extends across a junction.
 - 6.2.6 A diffusion area with less than 25 percent of the original width remaining.
- 6.3 Scribing Defects (100 × Min)
 - 6.3.1 Any chipout or crack which extends beyond 1.0 mil inside the scribe guidelines.
 - 6.3.2 Any crack which exceeds 5.0 mils in length or comes closer than 0.25 mil to an active metalization bonding pad or other active portion of the die.
 - 6.3.3 Any crack which exceeds 1.0 mil in length inside the scribe grid line that points toward active metalization or circuit area.
 - 6.3.4 Die having attached portions of the adjacent die that exceeds the scribe grid line by 5.0 mils.
- 6.4 Die Mount Defects
 - 6.4.1 Die not obviously flat with respect to header surface. (Must meet industry standards for high-frequency devices.)
 - 6.4.2 Die not oriented in accordance with applicable assembly drawings.
 - 6.4.3 Eutectic (gold silicon) particles attached to top surface of die or flowing over the top surface of die within 1.5 mils of an active area.
 - 6.4.4 Die not attached to substrate, and fails 4.0-ounce push test.
 - 6.4.5 Preform not completely wetted out and does not exhibit flow and with a gap between the preform and chip and chip and header.
 - 6.4.6 Eutectic fillet not surrounding die by at least 90 percent.
 - 6.4.7 Die cracked, chipped, or shorted by die mounting procedures.
- 6.5 Wire Bond Defects
 - 6.5.1 Less than 50 percent of bond on bonding pad. (High reliability 75 percent)
 - 6.5.2 Bonds placed so that wires from the bond pass over another bonding pad.
 - 6.5.3 Less than a 0.2-mil separation between bond and adjacent metalized or active area not electrically connected to bond.
 - 6.5.4 Wire bond missing.
 - 6.5.5 Open wire bond.

TABLE II. VISUAL INSPECTION CRITERIA (Continued)

- 6.5.6 Not wired according to applicable assembly diagram.
- 6.5.7 Wire tail longer than the diameter of wire used.
- 6.5.8 Land bond squashed out less than 1.2 times the original wire diameter and more than 2.0 times the original wire size.
- 6.5.9 Bond distorted to cause weakness with pull less than 2.0 grams on 1-mil wire and 3.0 grams on 2-mil wire.
- 6.5.10 Wire bond splash directed away from the active area shall not exceed 1 mil in its greatest dimension.
- 6.6 Bond Wire Defects
 - 6.6.1 Bond wire crosses closer than 0.2 mil to active metalization of die.
 - 6.6.2 Nicks, cuts, crimps, or scoring of wire which reduces wire diameter by 25 percent.
 - 6.6.3 Broken bond wires.
- 6.7 Wire Loop
 - 6.7.1 No excessive stress to cause wire breakage during temperature cycle with a minimum loop of 1.5 mils, above the highest mounting plane.
 - 6.7.2 No excessive loop that may cause a clearance of less than 1/2 the chip thickness at the lowest point of the wire loop.
 - 6.7.3 The wire loop height shall not exceed 5 mils above the highest mounting plane using a 1-mil wire, and 5 mils when using 2-mil wire.
 - 6.7.4 Wire bonding shall clear the active region at the edge of the chip by 0.1 mil minimum.
 - 6.7.5 Bond attempts--only one bond attempt on each pad is acceptable.
- 6.8 Contamination
 - 6.8.1 Unattached metallic, abrasive, or conductive material on the surface of the die, or within the package.
 - 6.8.2 Foreign material bridging isolated strips of metalization.
 - 6.8.3 Evidence of corrosion of the interconnecting metalization.
- 6.9 Product Acceptance/Rejection
 - Upon completion of the visual inspection, each lot traveler is required to be completed and include:
 - 6.9.1 Amount inspected.
 - 6.9.2 Amount accepted.
 - 6.9.3 Date completed.
 - 6.9.4 Inspector's stamp (inspector performing the visual inspection)
 - 6.9.5 Disposition of the rejected transistors.

F. Resistors

In the design of resistors for microwave applications, the material, geometry, frequency characteristics, power dissipation and range of values must be considered. A number of the resistors in microwave circuits are used in the bias networks and are isolated from the rf circuit. The design of these resistors is compatible with the techniques used in the design and fabrication of low-frequency resistors. In many cases, the bias circuitry is fabricated on substrates separate from the rf circuit substrate, avoiding potential processing compromises. This subsection is limited to resistor elements which are used in the rf portions of the microwave circuit.

1. **Material**—The composition of the resistor material should be homogeneous and uniform so that any design parameter needed to compensate for the departure from a lumped-resistor element may be effective. The material resistivity should be uniform with frequency for applications operating over wide frequency bands.

The most common materials employed as thin-film resistor elements have been tantalum nitride and Nichrome. Nichrome is invariably coated with a dielectric material such as silicon oxide for environmental and mechanical protection. Other materials such as chromium, rhenium, and cermets have been used as thin-film resistors. Thick-film resistors have been used with satisfactory results.

2. **Geometry**—The dimensions of the resistor element should be maintained as small as possible, consistent with the power-dissipation requirements, to approach the characteristics of a lumped-circuit component. In all cases, it is desirable that the physical dimensions be small when compared to a wavelength in the substrate material. The resistor should have a rectangular cross section. Bends or zig-zags in the resistor pattern should be avoided to minimize resistor capacitance and inductance. Tapered or semicircular radial patterns may be used for microwave loads with low VSWR across specific frequency ranges. Resistor elements which vary widely in shape and area due to the type of adjustment employed should generally be avoided since the high-frequency electrical performance is normally affected adversely. Thin-film resistors which are trimmed to value by electrolytic anodization remain constant in area during the adjustment process.

3. **Frequency Characteristics**—The frequency variations of microwave resistors must be determined for use in the circuit design. The resistor material, geometry, substrate, and ground plane are factors which influence the frequency performance of a microwave resistor. Inductance is determined primarily by resistor geometry. In general, the length-to-width ratio should be low and the length should be small when compared to a wavelength in the substrate material. Capacitance is determined by the dielectric constant and thickness of the substrate material, the resistor area and the ground-plane configuration. It is usually desirable to minimize the stray capacitance in microwave resistors.

4. **Power Dissipation**—The allowable power dissipation of a microwave resistor is determined by the temperature aging characteristics of the resistor material, the thermal properties of the substrate material, the maximum allowable surface temperature and the resistor geometry and area. Since these factors differ widely for specific design conditions, it is not feasible to arrive at a general rule for maximum power dissipation (watts per square inch) with any degree of accuracy. It is desirable that thermal profiles of the resistor elements be determined during design for the required power dissipation in the actual design configuration.

5. **Range of Values**—In view of the low-impedance levels normally associated with microwave circuits, the range of values for resistive components is usually from a few hundred ohms down to 1 ohm. The tolerances for units used as rf loads and impedance matching are usually very low; thus, the resistivity and dimensional controls must be quite accurate.

G. Inductors

The use of thin-film inductors is usually desirable and, in many instances, is essential to the design and fabrication of microwave hybrid microcircuits. These inductors take many forms such as square- and round-spiral flat coils, wavy lines, straight lines and tapered lines. Other geometrical aspects of spirals include conductor width, conductor spacing, number of turns, and the inner-to-outer diameter ratio. The conductor materials and thickness, the substrate dielectric constant, surface finish and thickness, and the absence or presence of a ground plane and points must be considered for inductor design purposes.

Several factors enter into the choice of the type of inductor to be used in a specific application. These factors include the design frequency and bandwidth, the available space and the required inductance value. Spiral coils which approximate the characteristics of lumped elements are useful up to the lower S-band region. Straight or wavy transmission-line segments are satisfactory as low-value or quarter-wave inductors up to the higher microwave frequencies, but have the disadvantage of relatively narrow operational bandwidth. Tapered transmission lines are used for fabricating elements with increased bandwidth capability at higher frequencies.

1. **Thin-Film Coils**—Round spiral coils have greater inductance than square coils for a given surface area, and they have higher Q s. Rectangular forms have less inductance and lower Q s than square forms.^{12, 13} The ratio of the outer diameter to the inner diameter should be five for optimum Q .¹²

Conductor materials should be low resistivity (less than 10×10^{-6} ohm-cm) to minimize ohmic losses and conductor thickness should be a minimum of two to three skin depths.¹³ Silver, copper, gold and aluminum are suitable materials for use as conductors. The choice of a specific material is normally based on associated processing and assembly operations. Selectively plated gold over evaporated chromium-gold has been found to be one of the most appropriate metalization systems for the fabrication of microwave hybrid microcircuits.^{4, 14, 15, 16, 17, 18}

Spiral conductor width and spacing are determined by considering several effects. Q is improved by increasing width with the same average radius. Reduced spacing leads to self-resonance effects which are the results of parasitic interturn capacitance. Increasing width and spacing increases the coil size and the result is loss of effectiveness as a lumped component.^{12, 13} The surface finish of substrate material should be much less than the conductor thickness to prevent an increase in conductor loss. Substrate surface smoothness and plating finish become more important in improvement of Q at frequencies of 2 GHz and above.⁶ The ground plane effect is to reduce the self-resonance frequency and this effect is enhanced by the use of high dielectric-constant substrate materials. The use of high-dielectric substrate also increases the parasitic interturn capacitance.

2. **Distributed Inductors**—Inductors can be formed, using segments of transmission lines. A short-circuited line of less than a quarter-wavelength will appear as an inductive element. A meandered line is often used to reduce the length of the desired line. The use of these linear

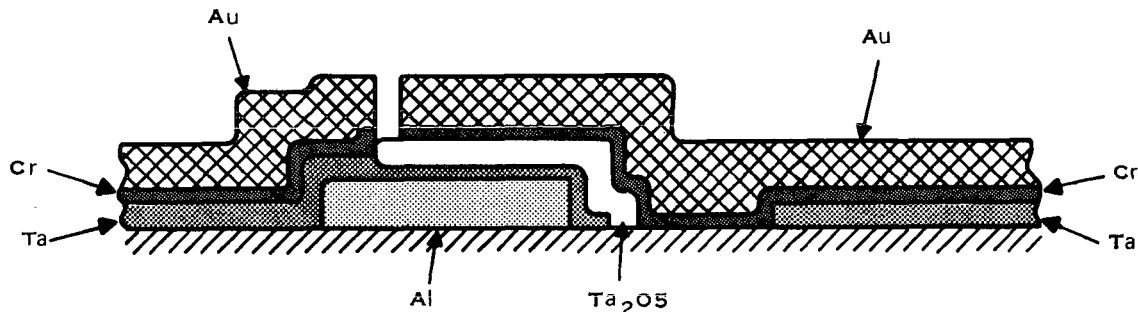
patterns as inductors is limited primarily to narrowband applications because of significant variation in impedance with frequency. Tapered conductors and transmission lines can be used as distributed elements for broadband applications at frequencies beyond the range of effectiveness of lumped-element spiral patterns.¹⁹

H. Capacitors

The use of capacitors is usually essential in the design and fabrication of microwave hybrid microcircuits. At the lower frequencies, up to approximately 2 GHz, capacitors can be used as lumped elements in matching networks. Capacitors also provide coupling and bypass functions in microwave hybrid microcircuits. The use of capacitors in microwave circuits requires a knowledge of the capacitor's characteristics, specifically, the loss tangent or Q, the dielectric constant, the breakdown voltage and series inductance.

1. **Chip Capacitors**—High-dielectric-constant chip capacitors are one of the most effective solutions for obtaining capacitance in microwave hybrid microcircuits. The chip capacitor offers a high degree of reliability and ruggedness, wide capacitance range, high volumetric efficiency and relative low cost. Chip capacitors with procelain as a dielectric provide excellent low loss lumped elements for networks up to approximately 2 GHz. Either NOP or porcelain capacitors may be used as blocking or bypass capacitors up through X-band.

2. **Thin-Film Capacitors**—Thin-film capacitors are fabricated with a variety of process and various dielectrics. Two of the more common dielectrics used are tantalum pentoxide, Ta_2O_5 , and silicon dioxide, SiO_2 . A typical thin-film microwave capacitors is shown in Figure 3.



155232

Figure 3. Microwave Capacitor Structure

The thin-film capacitors may be fabricated on the same substrate along with the microwave circuit metalization pattern. This technique requires a multistep process but usually results in superior capacitors at very high microwave frequencies. Thin-film capacitors may be fabricated on a separate substrate, usually silicon, with beam leads. The thin-film beam-lead capacitors are then attached to the particular microwave circuit with conventional bonding techniques.

3. **Distributed Capacitors**—Over narrow bands of microwave frequencies, through X-band, lumped-element capacitors can be approximated with short open-circuit low-impedance transmission lines. RF bypasses are commonly implemented in microwave circuits with open-circuited quarter-wave transmission lines over relatively narrow bandwidths.

I. Packaging

The primary purpose of a microwave hybrid microcircuit package is to provide protection to the circuit against moisture and other contaminants. To accomplish this, a hermetic seal is of great importance. The optimum approach would be to have passivated devices for protection during assembly operations, and a hermetic package for the overall circuit. The microwave package may be sealed with certain epoxies if the package was designed properly and if care is taken during sealing operations. Solders may be used to provide excellent seals, but care must be taken to prevent flux contamination during sealing operations. Generally, a microwave package should have an "out gas" hole to ensure good sealing yields.

Circuit packaging density is being increased as advances are made in hybrid microwave circuits. This density increase demands that thermal requirements be considered when designing packages and system applications. Careful internal design control is required to prevent hotspots at device and component locations. Thermal profiles of circuits should be obtained under typical rf operating conditions. Device peak temperatures should be measured, using a radiometer with a resolution of approximately 0.001 inch.

SECTION III

LIFE TEST AND FAILURE MODES OF MICROWAVE COMPONENTS AND CIRCUITS

A. Introduction

The design and quality standards for microwave hybrid microcircuits were established using current practices and knowledge. The development and processing of this type of microcircuit has involved novel and rapidly changing technologies. The scope of reliability data available was of a limited nature. Thus, additional data were collected and evaluated from recent reliability tests on thin-film capacitors, microwave transistors and microwave hybrid microcircuit modules. The tests and their results are presented in the following subsections. A summary of the reliability tests is given in Table III.

**TABLE III. MICROWAVE COMPONENT AND HYBRID MICROCIRCUIT
LIFE TEST**

Unit Under Test	Life Test	Test Condition
Thin-film tantalum capacitor, (Ta)	DC life	20 volts, 85°C ambient (4X operating voltage)
Beam-lead tantalum pentoxide capacitor, (Ta ₂ O ₅) MDO 823	DC life	20 volts, 85°C ambient (4X operating voltage)
Beam-lead silicon dioxide capacitor, (SiO ₂) MDO 830	DC life	20 volts, 85°C ambient (4X operating voltage)
MSC 3005 transistor	DC life	V _{CE} = 7Vdc, I _c = 0.37A T _{SINK} = 175°C, T _J = 200°C
HP 35821E	DC life	T _{AMB} = 140°C, T _J = 175°C P _{DISS} = 0.2 W
Microwave receiver microcircuit	DC life	T _{AMB} = 125°C; 5V, 15 mA
Integrated solid-state transceiver, (ISST)	RF operating	P _{OUT} = 40 W

B. Microwave Semiconductor

The major reliability problem area in microwave hybrid microcircuits has been in the microwave transistor.²⁰ This is particularly true for the microwave power transistor. Particular emphasis was placed on the MSC 3005 S-band power transistor and the HP 35821E transistor life tests.

A total of fifteen MSC 3005 transistors were subjected to a high-temperature life test for 2,700 hours. The MSC 3005 is a 3-GHz, 5-watt, 28-volt transistor with a thermal resistance of 8.5°C/W. The transistor has a four-cell matrix geometry with glass-passivated aluminum metalization. The transistor was biased at 7 volts, collector-emitter, and 0.37-ampere collector

current and then was operated for 2,700 hours at a heatsink temperature of 175°C. The junction temperature was approximately 200°C with the 175°C heatsink temperature and 2.59-watt dissipation. The transistors were initially checked for rf power. The following parameters were checked at the start of the burn-in and at 1,000-, 2,000- and 2,500-hour intervals; BV_{CBO} collector-to-base breakdown voltage, BV_{EBO} emitter-to-base breakdown, h_{fe} forward current ratio, and R_{BE} forward resistance of the emitter-base junction. In general, the only significant variation observed after 2,500 test hours is an increase in h_{fe} and the forward resistance of both collector-base and emitter-base junctions. Device number 37 had a significant increase in BV_{EBO} and a drop in h_{fe} . Eleven devices had collector-base forward resistance increase from 0.5 to 1.0 ohm. The emitter-base junction forward resistance increased from 0.3 to 0.5 ohms in eleven devices. The typical forward resistance for both junctions was initially in the 2.3- to 2.7-ohm range. The h_{fe} increased slightly on most of the devices tested, but three increased by factors of 28 to 45 percent.

RF test results on the MSC 3005 transistors indicate that device number 37, which had the low h_{fe} after 2,700 test hours also had low output power. The other devices were capable of a 5-watt output but, in general, had lost approximately 0.5 dB in gain.

Three groups of 35821E Hewlett-Packard microwave transistors, totaling 465 devices, were run in a high-temperature operating life test. The 35821E is a low-noise, high-gain ($NF = 6.5$ dB, and gain = 9.5 dB at 4 GHz), microwave transistor with a device dissipation rating of 700 milliwatts at a 126°C case temperature and 100 milliwatts at 175°C case temperature. The devices were divided into three groups, biased for 200-milliwatts dissipation, ($V_{CE} = 10$ volts, $I_C = 20$ mA) and were operated in an ambient temperature of 140°C. At this ambient temperature and power dissipation, the average junction temperature was in excess of 175°C. The first group of parts (386 units) were operated in this manner for 168 hours without catastrophic failures. A second group of transistors (39 units) were tested for 1,250 hours without failures. A third group of 40 transistors were run for 1,668 hours without failures. In summary, a total of 180,318 device hours were run under high-temperature operating conditions without failures.

C. Microwave Capacitors

The use of capacitors is usually essential in the design and fabrication of microwave hybrid microcircuits. Thin-film monolithic tantalum capacitors and beam-lead silicon dioxide and tantalum pentoxide capacitors were tested under high ambient temperature (85°C) and bias voltage (20 volts) conditions. A brief description of the capacitors under test, the test conditions and the results are discussed in the following subsections. The data are presented in Appendix D.

1. **Thin-Film Monolithic Tantalum Capacitors**—The thin-film monolithic capacitors tested used tantalum pentoxide, Ta_2O_5 , as the dielectric. The process employed in fabricating the thin-film capacitors is listed below.

- a. Selective glazing of ceramic substrate.
- b. Successive deposition of aluminum and tantalum; aluminum deposited by a high-vacuum evaporation technique is used to form a low-impedance bottom electrode. The tantalum was deposited by sputtering.
- c. After tantalum etch, the Ta_2O_5 dielectric was formed by a high-voltage anodization process.
- d. The top conductor was formed by a selective gold-plating operation.

Seven monolithic tantalum capacitors were fabricated in a microwave receiver circuit. The capacitors were connected in parallel on five receiver substrates and the total leakage current was measured. The capacitors were then tested for 3,000 hours with 20 volts dc applied at an 85°C ambient. The leakage currents were measured at 1,000-hour intervals. After 3,000 hours of high-temperature burn-in, one of the five receiver circuits exhibited a high leakage current. Analysis of that circuit indicated that one of the seven capacitors developed a short circuit due to dielectric breakdown. When the defective capacitor was isolated from the circuit, a 0.06-milliampere leakage current at 30 volts was measured. The data run on these circuits is presented in Table IV.

TABLE IV. HIGH-TEMPERATURE AND HIGH-VOLTAGE MONOLITHIC TANTALUM CAPACITOR LIFE TEST

Number	Initial	Leakage Current in μ A at 30 Volts		
		1,000 Hr	2,000 Hr	3,000 Hr
4	1.787	2.1	10.3	7.0
7	1.2	7.6	5.4	5.4
41	0.13	4.1	10.7	4.4
42	0.0055	0.36	0.32	0.36
43	1.75	10.5	9.2	0.06*

*Initially shorted at 3,000 hours. Reading is leakage current with shorted capacitor isolated from the circuit.

In summary, a total of 104,000 device hours were accumulated before the first failure. The calculated failure rate exhibited by these 35 monolithic thin-film capacitors is 0.96 percent/1,000 hours.

2. **Beam-Lead Tantalum Capacitors**—The 150-picofarad thin-film beam-lead tantalum capacitors tested were essentially the same as the monolithic tantalum capacitors described earlier. The major difference between the two was that the beam-lead capacitors were fabricated on a silicon substrate. The capacitors were tested with 20-Vdc at 85°C for 2,000 hours. The leakage current was monitored at 1,000-hour intervals for variation. A total of 100 capacitors were mounted for life test and one was damaged in handling. Two of the remaining 99 capacitors shorted within the first 1,000 test hours, resulting in an overall failure rate of 1.03/1,000 hours for the test. If 2,000-nanoampere leakage current is established as a failure limit (typical leakage is in the 20-nanoampere range), there were nine failures in the first 1,000 test hours and one in the second 1,000 hours. With this failure criteria, the calculated failure rate is 5.6 percent/1,000 hours.

3. **Beam-Lead Silicon Dioxide Capacitors**—One-hundred silicon dioxide (SiO_2) capacitors were subjected to the same test as the tantalum capacitors, 85°C ambient and 20-Vdc for 2,000 hours. Three of the capacitors were broken during measurements. No catastrophic failures were experienced during the test. Initially, the maximum leakage current at 30 volts in one group of 50 capacitors was 8.4 nanoamperes. In the second group of 50 capacitors, the maximum leakage was 2.2 nanoamperes. After a 2,000-hour burn-in, one capacitor in the first group had a 22-nanoampere leakage current and one capacitor in the second group developed a 150-milliampere leakage current.

Silicon dioxide capacitors can be fabricated by several processes. These include the reactive sputtering of silicon in argon to form the SiO_2 , rf sputtering of quartz, and thermally-deposited oxide using silane, SiH_4 .

Reactive-sputtered silicon produces silicon dioxide capacitors with the highest quality. This is a slow process and control of the dielectric thickness (capacitance tolerance) is very difficult to maintain. RF-sputtered quartz is also a slow process. The deposited process is fast, and uniform control of the dielectric can be maintained. Capacitors fabricated with deposited techniques have been found to have the poorest quality and reliability. The SiO_2 capacitors tested during this program were fabricated using the thermally deposited oxide technique.

It is generally desirable to use chip capacitors in microwave hybrid microcircuits wherever possible. At the higher microwave frequencies, thin-film beam-lead capacitors must be used. The use of a particular type of capacitor is dependent on the loss tangent and fabrication process. A 168-hour burn-in at 85°C with a 10-nanoampere maximum leakage current criteria for tantalum and silicon dioxide capacitors appears to be an acceptable burn-in criterion for reliable capacitors.

D. Microwave Receivers

Twenty-two X-band microwave hybrid microcircuit receiver circuits were fabricated in accordance with established microwave reliability and design standards. These units were placed on an operating life test at an elevated temperature, 125°C . The purpose of the test was to establish additional design, screening, and/or derating criteria which may be required to provide highly reliable microwave hybrid microcircuits.

The X-band microwave receiver circuit consisted of a front-end limiter, a balanced mixer and a two-stage preamplifier. Half of the receivers were built using open-chip transistors and the other half were fabricated using hermetically-sealed transistors. A photograph of the receiver circuit is shown in Figure 4 and a schematic is shown in Figure 5. This circuit contains the following thin-film components, chip or beam-lead devices, and transistors.

Transistors	2
Microwave thin-film capacitors	7
Thin-film resistors (Ta)	15
Microwave beam-lead diodes	2
Microwave chip diodes	2
Microwave chip capacitors	2

The microwave receivers were fabricated in three different groups and were subjected to a high-ambient, 125°C , operating life test. Test-data noise figure and preamplifier bias current measurements were taken at intervals of 168 and 500 hours and at each 500-hour interval until the end of the test. At the 1,500-hour interval, failures were observed in the three groups. Group 1 had 1,500 operating hours, group 2 had 1,000 operating hours and group 3 had 168 test hours. Failure analysis on the inoperative units revealed that a severe over-temperature condition was obvious. The solder holding the alumina substrates to the package floor had melted and had run through the plated-through circuit ground holes. The solder had run over the surface of the circuits causing shorts. The epoxy material in the package dc feedthrough pins had been

displaced. The temperature chamber was checked and was found to be operating normally. The over-temperature control was set for an indicated 150°C, which is near the melting point of the indium solder used in circuit assembly. It is surmised that the prime controller malfunctioned and the over-temperature control did not have enough margin to prevent damage to the circuits. As a result of this malfunction, the test was invalidated at 1,500 hours. Further testing of these units would have been inconclusive.

A review of the data, taken on the first and second receiver circuit groups before the chamber malfunction occurred, showed no confirmed failures in either groups. At the time of the data review, the nine units in the first group had accumulated 9,000 total test hours and the second group had accumulated 2,500 hours. At the 168-hour point, one unit in group 2 was a suspected failure and was removed from test. Failure could not be confirmed when measurements were made on the unit. A summary of the data for the three groups is presented in Table V.

E. Microwave Integrated Solid-State Transceiver

The microwave integrated solid-state transceiver (ISST) is a microwave hybrid microcircuit produced by Texas Instruments for use in a fractional phased-array investigation. The module is a 40-watt L-band transceiver. It consists of a three-stage L-band amplifier and circulator, solid-state input and output TR switches and TR switch logic, a low-noise L-band receiver preamplifier, and a four-bit solid-state phase shifter and logic control circuits. Figure 6 is a functional block diagram of the ISST module.

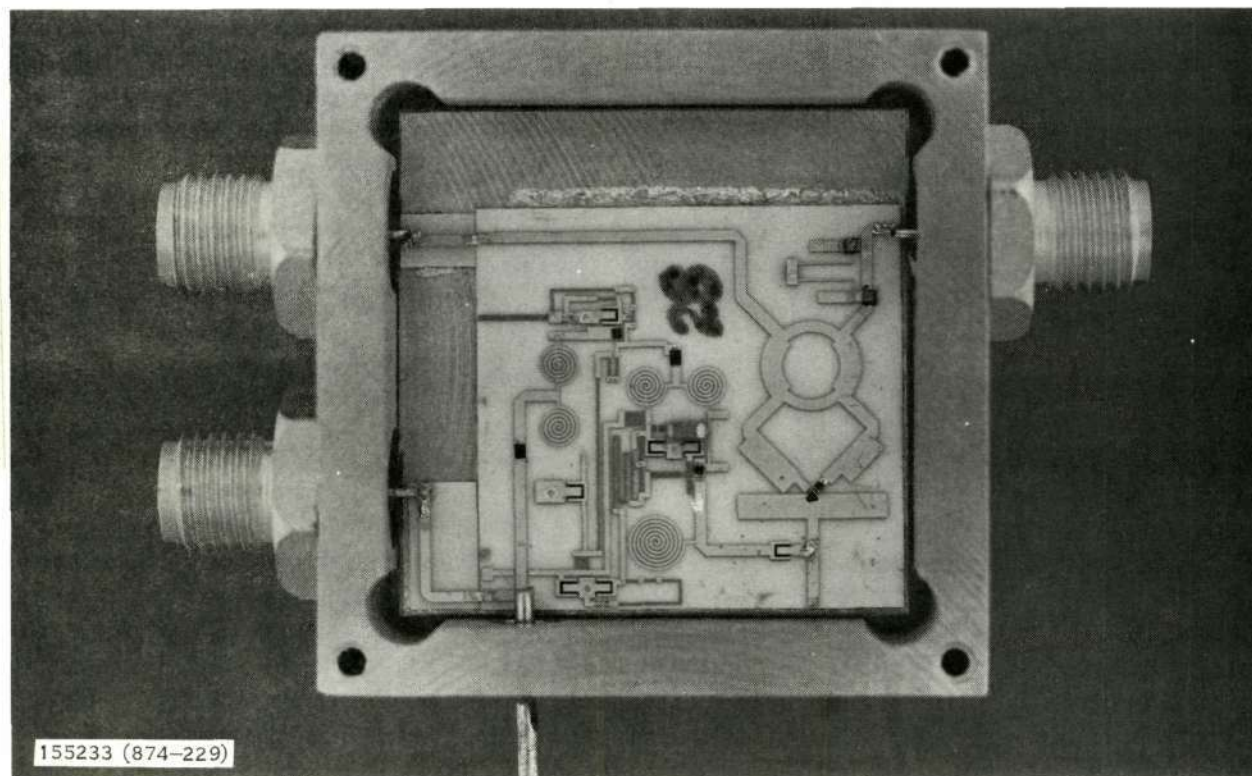
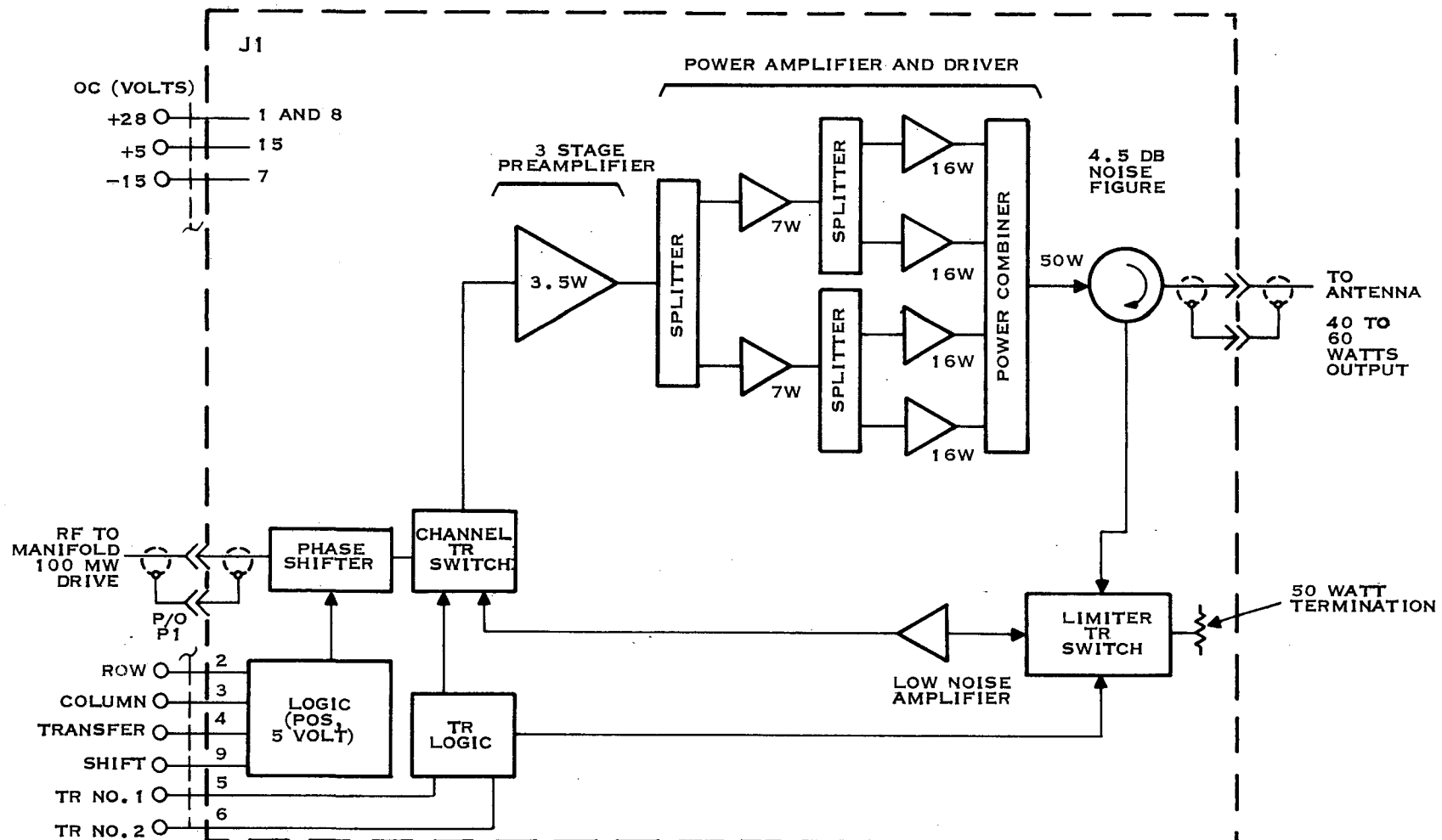


Figure 4. Microwave Receiver Circuit

TABLE V. X-BAND RECEIVER 125°C BURN-IN DATA

Group	Rcvr No.	Initial		168 Hr		500 Hr		1,000 Hr		1,500 Hr		
		NF	I(mA) at 5 Vdc	NF	I(mA) at 5 Vdc	NF	I(mA) at 5 Vdc	NF	I(mA) at 5 Vdc	NF	I(mA) at 5 Vdc	
I	11	12.5	14	7.95	12	7.15	12.5	7.3	12.0	7.45	11.5	Sig and L.O. Conn. Bad
	14	13.3	13.5	9.6	12.5	8.6	13.5	8.6	12.0	8.8	11.5	
	15	13.95	15	10.3	14	9.6	14.5	9.6	14.5	9.8	12.5	
	20	12.75	12.5	8.75	12	8.2	12.5	8.4	11.2	8.6	10.5	
	24	14.6	13.5	11.7	13	11.95	13.5	11.4	12.0	11.4	11.5	
	25	13.8	12.5	11.3	12	11	12	10.75	11.5	10.8	10.5	L.O. Conn. Bad
	28	12.4	13.5	7.85	12.5	7.7	13	7.9	11	8.05	11	
	33	12.45	12.0	8.7	11.5	8.2	11.5	8.5	11.2	8.8	10	L.O. Conn. Bad
	34	15.7	12.5	13.4	12	11.8	12.5	11.2	11.2	15	10.5	
II	9	7.55	13.5	7.55	13	7.45	12.5	Shorted				
	13	7.85	12.5	7.8	12.5	7.9	11.6	7.9	9.9			
	16	13.35	13	13.35	13	13.35	12	13.35	12.5			
	19	7.8	14	7.45	14	7.65	13	8.6	12			
	26	9.0	9.5	9.7	7.5	Unconfirmed Failure						
	29	6.6	14	6.9	14.5	6.95	14.5	Shorted				
III	108	9.8	14.0	9.95	13.5							
	110	8.6	12.5	8.25	12.0							
	111	7.8	13.5	7.6	12.5							
	112	8.9	13.5	8.3	12.0							
	113	8.8	15.0	L.O. Connector Open								
	114	9.7	13.5	9.1	10.5							
	116	6.65	13.5	6.35	12.0							



155235

Figure 6. ISST Module

TABLE VI. ISST COMPONENTS

ISST Device Type	Quantity
Microwave Transistors	
MSC 2010	4
MSC 2005	2
MSC 2003	1
TI 13S	3
TI 25S	1
Avantex 640A	1
Integrated Circuits	
TI-SN5480	1
TI-SN5472	1
TI-SN5404	1
TI-SN54H40	4
TI-SN5475	1
TI-SN5495	1
TI-SN75480	2
Transistors—bipolar	
SSB 9799	1
SSC 0199	1
Diodes	
TI-MD100 PIN	2
TI-MD101 PIN	16
TI-MD0819 varactor	3
Capacitors	
NFO ceramic chip	22
Porcelain chip	28
Thin-film (Ta)	20
Beam lead (Ta)	16
Resistors	
Thin-film (Nichrome)	23
Thick film	19

A list of the components used in the ISST module is shown in Table VI. The active devices in the module include 12 microwave transistors, 2 bipolar transistors, and 11 integrated circuits. The components are used in 31 different microwave microcircuits fabricated on alumina substrates which, in turn, are mounted on 5 gold-plated molybdenum carrier plates. The receiver and transmitter carrier plates are then mounted on opposite sides of the module. A photograph of the transmitter is shown in Figure 7. The receiver side of the module is shown in Figure 8.

The assembly of the ISST module requires 352 beam-lead or strap-weld operations, 131 component alloying operations, 193 wirebonds, and 15 solder operations. To ensure good process yields and reliability, monitoring is performed at all levels. The microwave power transistors receive a 168-hour dc burn-in before assembling them into the unit. An outline of module screening after assembly is shown in Figure 9.

The ISST module burn-in is a duplication of actual phased-array operating conditions. Transmitter and receiver functions are exercised for 500 hours with a 22°C heatsink, a transmit pulsewidth of 500

microseconds and 20-percent duty cycle. A total of 37,438 burn-in hours were run on 78 ISST modules with only 8 failures. Component problems caused 4 failures, 3 monolithic digital integrated circuits and 1 chip capacitor, 4 failures were caused by faulty workmanship. The workmanship problems included 1 solder joint, 2 welds, and 1 case of contamination.

A total of 73,683 module operating hours have been obtained in the fractional array, and 10 failures were experienced. These modules have been analyzed and 6 failures were caused by component failures. Two component failures were caused by design overstress problems in the first two modules. This was corrected in later modules. Three of the component failures were found in digital monolithic integrated circuits which have been redesigned. One MSC 2010, a 10-watt microwave transistor, failed for unknown reasons.

In summary, the MTF exhibited by the ISST modules during burn-in was 4,679 hours. It is interesting to note that 50 percent of the burn-in failures were due to workmanship and 50 percent were due to component failures. Three of the component failures were due to a digital integrated circuit design problem which has been corrected. Sixty-percent of the field failures were the result of component failures and 40-percent were due to faulty workmanship.

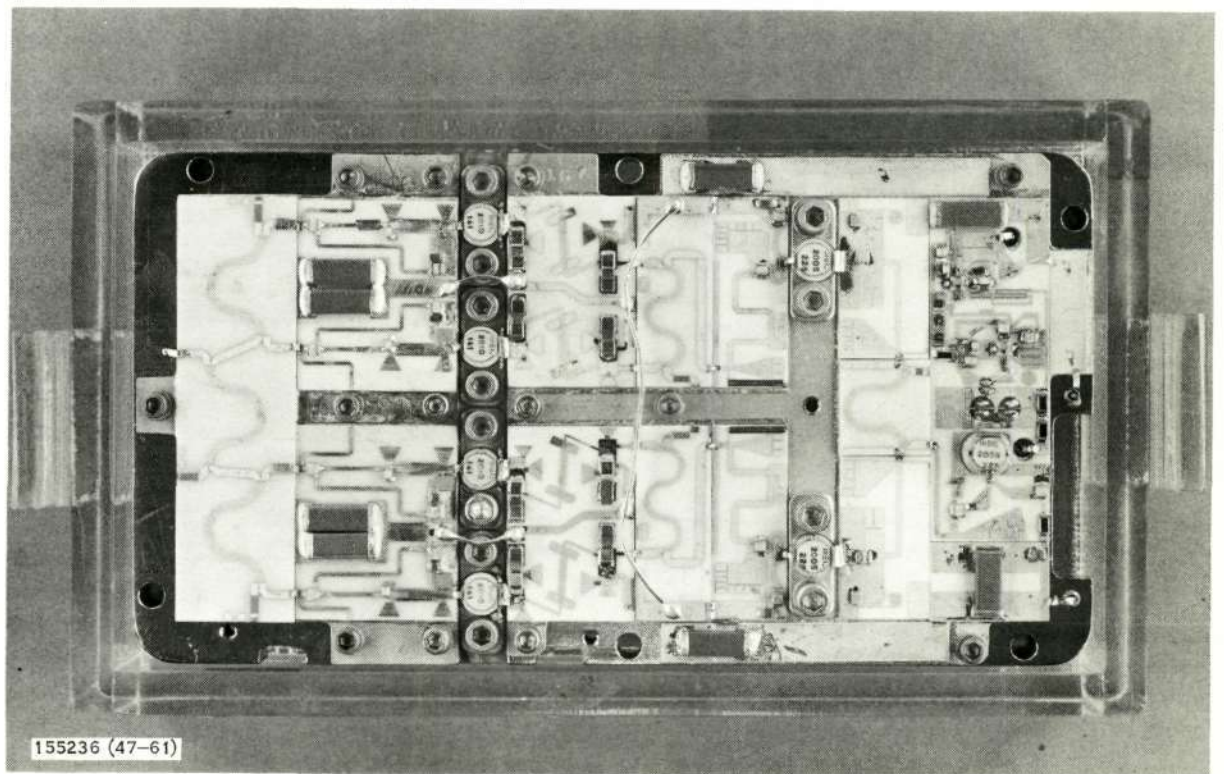


Figure 7. Module Transmitter

Reproduced from
best available copy.

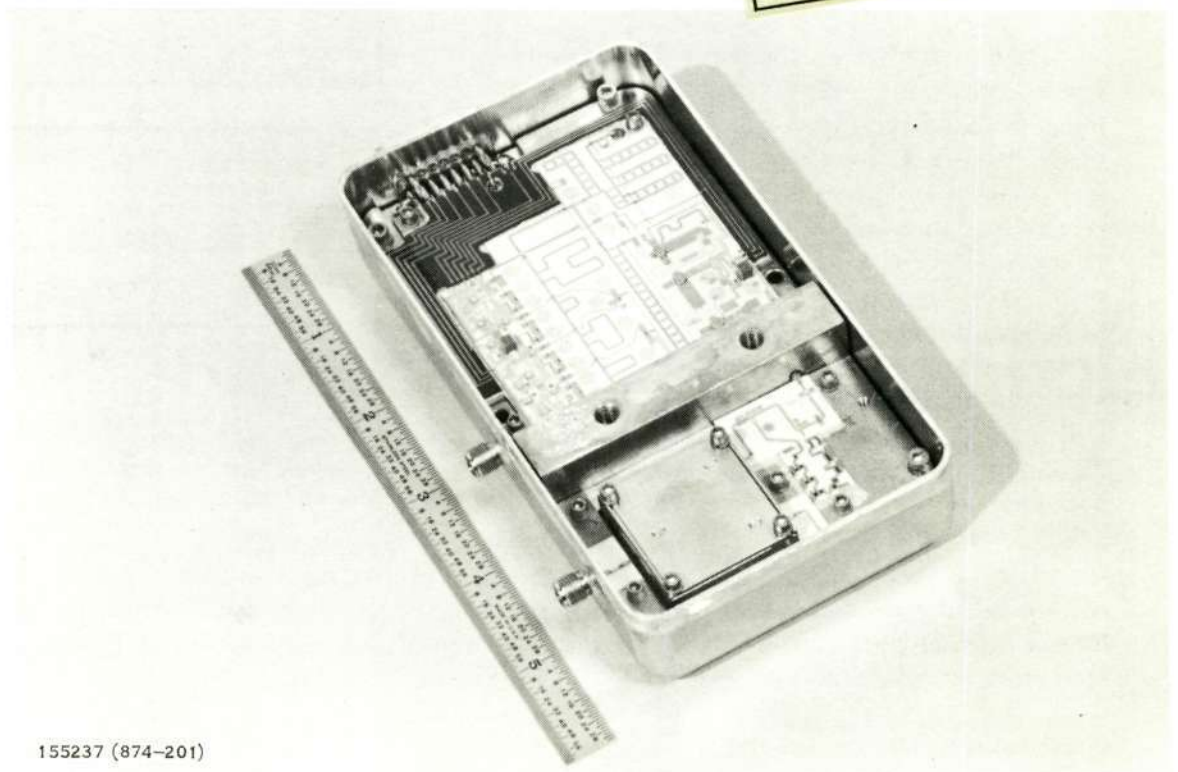


Figure 8. Module Receiver

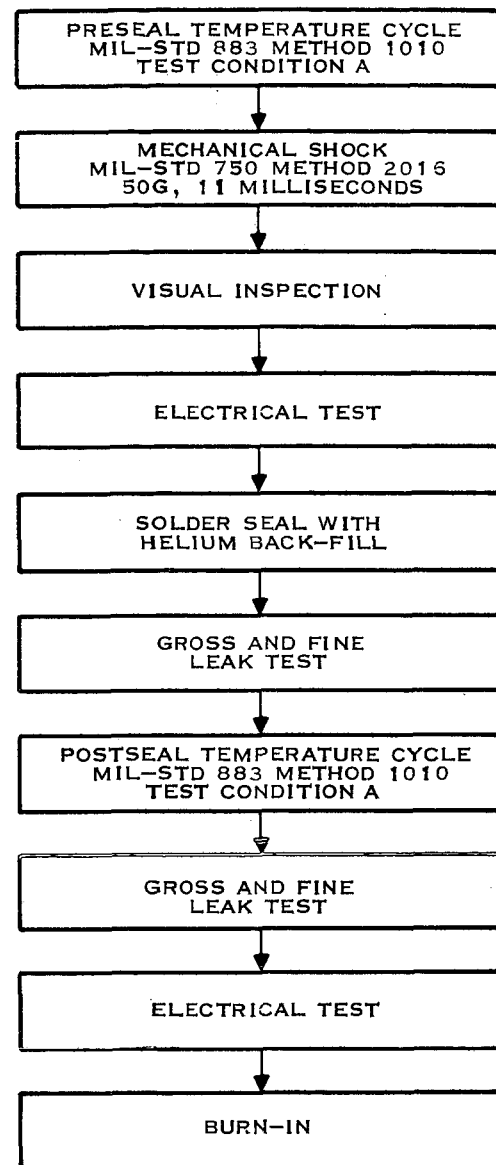
Five of the field failures were found to be due to overstress (MSL04 microwave transistor in the first two modules) or a component design problem (digital monolithic integrated circuit). Previous microwave hybrid integrated circuit modules have indicated problems with the microwave power transistors.²⁰ In this program, only one microwave power transistor failed with over 111,121 module operating hours.

F. Summary

Additional data were collected from reliability tests on thin-film microwave capacitors, monolithic and beam-lead types, microwave transistors and microwave hybrid microcircuits. A microwave capacitor (tantalum and silicon dioxide) life test indicated a 168-hour high-temperature burn-in with a delta leakage-current criterion is sufficient to eliminate unstable capacitors. In general, unstable tantalum and silicon dioxide capacitors will eventually break down.

The microwave transistor tests and results from the ISST module life test indicate that device improvements have been made. Proper device design, characterization and application is required for good circuit reliability. Because of the high junction temperatures and current density present in microwave transistors, a wear-out mechanism, electromigration, exists. This wear-out mechanism is well-documented and a design with reasonable lifetime can be achieved with adequate derating. A 168-hour dc screening test appears valuable in eliminating devices with defects.

The life test on microwave circuits, X-band receivers and the ISST module indicates that with good design techniques, screening criteria and assembly procedures, reliable microwave hybrid microcircuits can be built. Module screening after assembly with a 168-hour burn-in and temperature cycle is useful for determining workmanship problems.



155238

Figure 9. ISST Module Screening Flow Chart

REFERENCES

1. M.V. Schneider, et al., "Microwave and Millimeter Wave Hybrid Integrated Circuits for Radio Systems," *BSTJ*, July-August, 1969.
2. R.A. Pucel, et al., "Losses in Microstrip," *IEEE Transactions*, Volume MTT-16, No. 6, June 1968.
3. P. Throughton, "The Evaluation of Alumina Substrates for Use in Microwave Integrated Circuits," European Microwave Conference, 1969.
4. C.E. Earhart, "Microwave Integrated Circuit Fabrication," Electronic Components Conference, 1970.
5. A.J. Wahl, et al., "Transistors, Diodes and Components," *BSTJ*, May-June, 1970.
6. M. Caulton, et al., "Hybrid Integrated Lumped-Element Microwave Amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, July 1968.
7. M. Lemke, "Microwave Integrated Devices and Subsystems on Ferrite Substrates," European Microwave Conference, 1969.
8. Harold Sobol, "Applications of Integrated Circuit Technology to Microwave Frequencies," *Proceedings of the IEEE*, Vol. 59, August 1971, pp. 1200-1211.
9. James R. Black, "RF Power Transistor Metallization Failure," *IEEE TED*, September 1970 (Nippon Electric Co., "Failure Modes and Their Analysis," March 19, 1971).
10. Jim Humphrey, "Microwave Transistor Life Test," Collins Radio Company, Dallas, Texas.
11. "Wescon Technical Sessions," *Microwaves*, August 1971.
12. G.H. Dill, "Designing Inductors for Thin-Film Applications," *Electronics Design*, February 17, 1964.
13. Daniel A. Daly, et al., "Lumped Elements in Microwave Integrated Circuits," *IEEE MTT Transactions*, December 1967.
14. Frank T. Keister, "An Evaluation of Materials and Processes for Integrated Microwave Circuitry," *IEEE MTT Transactions*, July 1968.
15. Arthur H. Solomon, "Integrated Microwave Components and Subsystems Using Beam-Lead Semiconductor Devices," *WESCON*, 1968.
16. M. Caulton, "Thin Film Microwave Components," *NEREM*, 1968.
17. Meade M. Hower, et al., "A Hybrid Integrated Transistor Amplifier for High Volume Production," *IEEE MTT Conference*, 1969.
18. William Schilling, "The Real World of Micromin Substrates," Part 4, *Microwaves*, September 1969.
19. O.P. Rustog, "Linearly Tapered Transmission Line and Its Application in Microwaves," *IEEE Transactions on Microwave Theory and Techniques*, March 1969.
20. AFAL Technical Report No. TR-71-237, *Failure Modes and Mechanisms in Microwave Integrated Circuits*, Texas Instruments Incorporated, September 1971.

APPENDIX A
BIBLIOGRAPHY NOTES

A-1

BIBLIOGRAPHY NOTES

1. An Evaluation of Materials and Processes for Integrated Microwave Circuitry, IEEE MTT Transactions, July 1968, by Frank Z. Keister.
 - a. Substrate materials which gave optimum performance are sapphire, 99.9% Al_2O_3 and 99.5 - 99.7% Al_2O_3 in that order. Beryllia, glazed ceramic, quartz, and glass are poor materials to use for microwave applications.
 - b. Surface finish and purity of the substrate material are highly important.
 - c. The uniformity and value of the dielectric constant are important for design purposes particularly for distributed circuits.
 - d. Electroplated conductors and screened and fired ink conductors gave superior results. A minimum of four skin depths is recommended for conductors.
Note: A minimum of two skin depths is sufficient based on theoretical considerations. ¹
 - e. The best metallization process was evaporated chromium-gold plus electroplated gold.
2. Low-Noise Integrated X-Band Receiver, ISSCC, 2/15/68, L.S. Napoli, et al., RCA

¹
Ramo, Whinnery and Van Duzer, "Fields and Waves in Communication Electronics", page 299, John Wiley and Sons, Inc., 1965.

The authors describe the use of Cr thin film resistors, copper-SiO₂-copper capacitors, electroplated Ni-Au capacitor plates and interconnecting pads, thick film resistors, and 10-micron Cu plated over chromium flash microstrip in fabricating microwave circuits.

3. Ferrite Devices for Microwave Integrated Systems, ISSCC, 2/15/68, G.T. Roame, et al., Syracuse University.

- a. Phase shifters, serrodyne, circulators, isolators, and switches are described based on the use of ferrite materials.

4. Integrated X-Band Transceivers for Radar Applications, ISSCC, 2/15/68, A.G. Kramer, et al, Sylvania.

Conductor patterns were formed using Cr-Au evaporation followed by plating and screened and fired silver. No passive thin film components were fabricated on the substrate.

5. Thin Film Lumped Element Integrated S-Band Power Amplifiers, ISSCC, 2/68, S.P. Knight, et al, RCA.

Plated conductors were used for Hi-Q inductors (3) with values of 14-25 nh and SiO₂ was the dielectric material for thin film capacitors (5) with values of 0.8-40pf.

6. New Microwave Integrated Circuit Modules, WESCON, 1968, W.G. Matthei and William Crowe, Raytheon.

The subject circuit modules were fabricated using photo-etched conductors from fired silver or evaporated Cr + copper on alumina substrates.

BIBLIOGRAPHY NOTES, Page 3

7. Integrated Microwave Components and Subsystems Using Beam Lead Semiconductor Devices, WESCON, 1968, Arthur H. Solomon, Sylvania.
 - a. Beam lead diodes (only) were used in the assembly of the circuits.
 - b. Conductors were formed by selective gold plating over a thin layer of evaporated chromium-gold.
8. Microwave Integrated Circuit (MIC) Technology, Electrotechnology, October 1968, Philip L. Clar, Motorola.
 - a. The discussion was somewhat general.
 - b. The use of silicon, sapphire, and ceramic substrates was described together with thin and thick film technologies.
 - c. Gunn, LSA and IMPATT devices were considered for building microwave circuits.
9. Etched Thick Film Microwave Circuits, NEREM, 1968, H.E. Stinehelfer, et al, Microwave Associates.
 - a. A silver solution was fired on 96% Al_2O_3 ceramic to a thickness of 1/2 mil, etched and plated.
 - b. Capacitors were built from barium titanate glass using fired top electrode plus protective glass. A design value of one picofarad per square mil was used.

BIBLIOGRAPHY NOTES, Page 4

10. Thin Film Microwave Components, NEREM, 1968, M. Caulton, RCA.

- a. The substrate material utilized was 99.5% Al_2O_3 or sapphire.
- b. Conductors were formed from vacuum-deposited Cr-Au with selective plating.

11. The Real World of Microminiature Substrates, Microwaves, December 1968, William Schilling, Tek-Wave, Inc.

- a. Difference in dielectric loss between 96% and 99.5% Al_2O_3 ceramic substrate material is negligible.
- b. Cr-Cu metallization is only slightly lower in loss than Cr-Au.
- c. Substrate thickness has a substantial effect on circuit loss.
- d. Surface finish has a great effect on circuit loss.

12. Microstrip Technology, NEC, 1968, C.P. Hartwig, et al, Raytheon

Attenuation is related to substrate thickness and dielectric loss tangent, surface roughness and glaze, plating-thickness and resistance.

13. The Real World of Microminiature Substrates No. 3, Microwaves, March 1969, William Schilling, Tek-Wave, Inc.

- a. Impedance curves for 99.5% and 96% Al_2O_3 substrate material are presented.

BIBLIOGRAPHY NOTES, Page 5

14. Designing Lumped Elements into Microwave Amplifiers, Electronics, 4/14/69, M. Caulton, et al.

- a. Describes details of construction of lumped elements, i.e., inductors, capacitors, and resistors.
- b. Lists characteristics of common metals for thin film networks.
- c. Describes triple decker construction for lumped element networks.
- d. Recommends use of sapphire substrates.

15. Microstrip Lines for Microwave Integrated Circuits, BSTJ, May-June 1969, M.V. Schneider.

A theoretical discussion of microstrip characteristics is presented.

16. Microwave and Millimeter Wave Hybrid Integrated Circuits for Radio Systems, BSTJ, July-August 1969, M.V. Schneider, et al, Bell Labs.

- a. Substrate Material Characteristics
 - (1) Dielectric Constant
 - (2) Dielectric Loss
 - (3) Thermal Expansions Coefficient
 - (4) Thermal Conductivity

- b. Comparison of calculated versus measured results.
Typical example - polished quartz substrate.

$$\epsilon_r = 3.78$$

$$W = h = 0.75\text{mm} (0.030")$$

$$\tau \text{ (metal thickness} = 2 \text{ }\mu\text{meters)}$$
$$(80 \text{ }\mu\text{inches)}$$

$$\text{Attenuation at } 30\text{GHz} \approx 0.1\text{db/cm}$$

$$\text{Measured } Q = 450$$

$$\text{Calculated } Q \text{ (uniform current)} = 514$$

$$\text{Calculated } Q \text{ (non-uniform current)} = 840$$

- c. Typical Substrate Material Properties

<u>Material</u>	<u>Dielectric Constant</u> ϵ_r	<u>Loss Tangent</u> $\times 10^{-4}$	<u>Thermal Expansion</u> $10^{-6} \text{ } ^\circ\text{C}^{-1}$	<u>Thermal Conductivity</u> $\text{Watts/cm } ^\circ\text{K}$
Clear Fused Quartz	3.78	1	0.4	1.4×10^{-2}
Epoxy Glass				
Thiokol Panelite G10	4.4	80	10.0	1.6×10^{-1}
Corning 7040 Glass	4.5	73	4.8	1.1×10^{-1}
BeO Alsimag 754	6.0	40	6.0	2.3
Alumina Alsimag 772	9.5	1	6.0	3.7×10^{-1}

- d. Conductor Materials

- 1) Low RF sheet resistance.
- 2) Good adherence and high stability.
- 3) Bondable top surface.
- 4) Must be compatible with devices.
- 5) Uniform film thickness.

BIBLIOGRAPHY NOTES, Page 7

17. Integrated S-Band Parametric Amplifier, MTT, 1969, Robert S. Forman, American Electronics Laboratories.

a. In this article, it is stated that polished 99.5% Al_2O_3 gives appreciably lower insertion loss than as-fired Al_2O_3 .

18. A Hybrid Integrated Transistor Amplifier for High Volume Production, MTT Conference, 1969, Meade M. Hower, et al, BTL, Reading.

Evaporated gold over Ta_2O_5 - SiO_2 capacitor with plated gold on transmission lines was used in the building of this circuit.

19. Microwave Lumped Element Networks, Microelectronics Symposium, 1969, G.C. Piazza, et al, BTL.

a. Microwave filters were constructed using spiral inductors and interdigitated film capacitors. Q's of 50 - 100 for inductors and greater than 100 for capacitors.

20. Thin Film Chromium Resistors for Microwave Integrated Circuits, Microelectronics Symposium, 1969, Robert Brymer, et al, Sylvania.

a. Chromium is evaporated to desired resistivity followed by evaporated gold and plated gold. Gold is etched to expose chromium resistor except for trim area. Chromium is air baked to stabilize and then proper amount of additional trim resistor is exposed by etching to bring to value. Accuracy of 5% results.

21. Dielectric Loss in Integrated Microwave Circuits, BSTJ, September, 1969, M.V. Schneider.

Equations are given for determining the dielectric loss for microstrip transmission lines. The principal conclusion is that conductor loss is predominant for circuits constructed on high quality ceramic and quartz substrates.

22. Microwave Integrated Devices and Sub-Systems on Ferrite Substrates, European Microwave Conference, September 8 - 12, 1969, M. Lemke, Phillips, Hamburg.

Non-magnetic ferrites (curie temperatures much below room temperature) are useful as microwave network substrates where ferrites are employed. Magnetic and non-magnetic ferrite can be co-sintered to produce a substrate with discrete magnetic areas. Materials have less than 1% variation in λ/λ_0 from -20 to +60°C. The thermal conductivity is 10 times lower than alumina. The material can be easily machined and polished. Losses are comparable to alumina-based circuits.

23. The Real World of Micromin Substrates, Part 4. Microwaves, September, 1969, William Schilling, Tek-Wave, Inc.

- a. The substrate properties and metallization types, required for high-Q transmission lines, are considered:

- (1) High substrate purity is of utmost importance.
- (2) Surface finish is somewhat less important.
- (3) Thin films are better than thick films.
- (4) Chrome-gold metallization was the best overall combination.

b. Charts are presented giving the following data:

- (1) Unloaded Q vs frequency for gold and copper metallization on 99.5% alumina ceramic.
- (2) Metallization thickness versus frequency for gold and copper.
- (3) Loss per wavelength for various transmission line fabrication systems.

24. Thick Films or Thin?, IEEE Spectrum, October, 1969, Rudolf E. Thun, Raytheon

a. Tables are presented covering the following topics in detail:

- (1) Sputtering methods.
- (2) Etchants for selected deposited films.
- (3) Properties of bulk metals and alloys used for the preparation of thin-film components.
- (4) Deposition methods.
- (5) Comparison of integrated components in thick and thin-film technologies.

b. Article states that cost of developing a circuit is about 50% higher for thin than for thick films. However, manufacturing cost for complex hybrid circuits does not depend on film-deposition technology since the costs of added components, assembly and test are the controlling items. Conclusion is that selection of the best fabrication technique must be based on the available manufacturing resources and the given component and circuit specifications.

BIBLIOGRAPHY NOTES, Page 10

25. Arc Plasma Deposits May Yield Some Big Microwave Dividends.
Electronics, February 2, 1970, D.H. Harris and R.J. Janowiecki,
Monsanto.
- a. All types of materials including ferrites and high-K dielectrics can be deposited by this technique.
 - b. Deposition rates can be controlled from 4 microns/minute to 2 mils/minute.
 - c. Materials can be deposited on plastic substrates as well as alumina and beryllia ceramics.
 - d. Thickness tolerance of 10% can be controlled from 0.5 mil to 20 mils.
26. Well-made Coat..., Electronics, March 16, 1970
- a. Coating material is parylene (Chloro-p-xylylene).
 - b. Deposited in 1.2 - 2 mils thick layers.
 - c. Successfully subjected to 85°C, 85% R/H for 10 days.
 - d. Successfully passed high pressure, high temperature, moist saline test.
 - e. Oxidizes at high temperatures over extended periods.
27. New Style Beam Leads, Electronics, August 31, 1970, U.S. Reports

BIBLIOGRAPHY NOTES, Page 11

- a. Metallization system used is chromium-palladium-gold evaporation followed by gold plating to 0.5 mil. Sputtered platinum-titanium-gold caused an increase in threshold voltage.
 - b. Lazer scribing was used to separate chips in wafer-lazer beam penetrates 9 mils through 10-mil wafer.
28. Plastic MOS is Off and Running, Electronics, August 31, 1970, Peter Schuyten
- a. Beam leads are used to reduce cost and assembly time.
 - b. RCA, National Semiconductor and General Instruments are supposed to have the reliability problem associated with the plastic package solved.
29. Etched Thick Film Microwave Circuits, NEREM, 1968, H.E. Stinehelfer, Sr., A.T. Botka and W.J. Moroney, Microwave Associates
- a. Silver solution was fired on 96% alumina ceramic substrates (5 - 10 micro-inch ground finish).
 - b. The 0.5 mil thick silver metallization is photo-etched to form circuit pattern.
 - c. Gold was plated over the silver prior to mounting the actual components.

- d. Thick film capacitors are formed by firing high-K barium titanate glass, forming the top electrode (not detailed) and covering with a fired, protective-glass overlay. Capacitors have one pf per square mil with 500 volts breakdown.
30. The Evaluation of Alumina Substrates for Use in Microstrip Microwave Integrated Circuits, European Microwave Conference, 1969, P. Troughton, University College, London
- a. A method is described for measuring substrate loss factor and effective dielectric constant.
 - b. Measurements were made on alumina substrates with purity, surface finish and supplier as parameters.
 - c. Charts are shown presenting data on Q-factor and effective dielectric constant vs frequency for variables given in b.
31. How to Assemble Microwave IC's, Microwaves, August, 1969, Norman Tarawsky, HPA

This article describes the general processes for fabricating microwave integrated circuits. The following tables are included:

- a. Film materials and processes
 - b. Thermal expansion and conductivities of some typical materials.
 - c. Generalized comparison of typical thick and thin film network parameters.
 - d. Standard chip specifications (HPA devices).
32. Resin Systems for Encapsulation of Microelectronic Packages, Solid State Technology, August, 1970, Henry Hirsch, IBM

a. Describes a program to evaluate epoxy resin for packaging with emphasis on the following points:

- (1) Measurement of thermal expansion of filled and unfilled resin from -55°C to 220°C.
- (2) Determination of second-order transition temperatures on the resin systems.
- (3) Effect on curing temperatures on second-order transition temperature with emphasis on changing these temperatures to a higher level.
- (4) Effect of reactive diluents on thermal expansion and determination of ratios giving certain expansion characteristics.
- (5) Effect of specific fillers on thermal expansion and amounts of these materials which give minimum expansion over a designed temperature range.
- (6) Evaluation of epoxy resin systems and cured resins, filled and unfilled, for ionizables (chlorides), pH, conductivity, extract after reflux and dielectric changes resulting from exposure to humidity and pressure.
- (7) Examination of metallurgical bonds which are encapsulated with epoxy resins to determine reaction of materials and failure mechanisms after exposure to thermal cycling, temperature aging and electrical tests.

b. Specific performance degrading impurities are:

- (1) Ionic impurities - Na, etc.
- (2) Hydrolyzable chlorides
- (3) Impurities in fillers or other materials used in formulations:

Cu-Mg-Fe^{xxx} - Na-Mn-Pb-Si-Ga-B.

33. Ceramic Capacitors for Hybrid Integrated Circuits, IEEE Spectrum, January, 1969, Donald W. Hamer, Eric.

This article describes ceramic chip capacitors from the standpoint of:

- a. Manufacturing process
- b. Electrical characteristics
- c. Capacitance versus size.
- d. Cost
- e. Reliability
- f. Temperature effects on K, Q, conductivity and life
- g. Frequency effects
- h. Time effects
- i. Voltage effects
- j. AC effects

34. The Compatibility of Materials, IEEE Spectrum, January, 1969, Walter H. Kohl, NASA

Describes requirements for materials to retain physical, chemical and electrical properties under adverse environmental conditions.

35. Reliability of Beam-Lead, Sealed-Junction Devices, 1969 Annual Symposium on Reliability, D.S. Peck, BTL

The paper summarizes reliability tests on beam-lead, sealed-junction transistors and bipolar integrated circuits. Test conditions include accelerated temperature and power, reverse bias at accelerated temperature and accelerated humidity with reverse bias. The test results indicate that the beam-lead devices have considerable

greater median life hours than conventional silicon transistors and integrated circuits.

36. Linearly Tapered Transmission Line and Its Application in Microwave Theory and Techniques, March, 1969, O.P. Rustog, Jadavpur University, Calcutta.

Non-uniform transmission lines, specifically linearly tapered lines, are shown to have superior bandwidth characteristics compared to uniform lines. Equations are given for computing the properties of linearly tapered transmission lines.

37. Losses in Microstrip, IEEE Transactions on Microwave Theory and Techniques, June, 1968, Robert A. Pucel, Raytheon.

Equations are given and charts shown for determining the dielectric and conductor ohmic losses for microstrip transmission lines. Theoretical and experimental results are plotted for rutile and alumina. Good agreement between calculated and measured data is obtained for all but one case, i.e., that corresponding to the thicker substrate and higher w/h ratio.

For maximum circuit size reduction, substrates with dielectric constants of the order of ten or higher are being used.

38. Hybrid Integrated Lumped-Element Microwave Amplifiers, IEEE Transactions on Microwave Theory and Techniques, July, 1968, Caulton, et al, RCA.

- a. A description of the component and circuit design is presented.
 - b. Basic design rules for inductors state:
 - (1) Conductor thickness should be greater than 3 skin depths.
 - (2) Optimum ratio of outer diameter to inner diameter should be 5.
 - (3) The Q of a circular coil is higher than square or rectangular coil.
 - (4) At 2GHz, substrate surface smoothness and plating finish are important in improvement of Q.
 - c. Substrate material used was polished sapphire. Conductor material was selectively plated copper topped with gold or selectively plated gold. Measured Q's were 50-60 percent of calculated values. After accounting for dc resistivity of plated metal, measured Q's were about 2/3 of theoretical values.
39. Metallization Systems for Integrated Circuits, NEPCON, Richard W. Wilson and Lewis E. Terry, Motorola.
- a. The metallization characteristics should be:
 - (1) High conductivity - $\rho < 10 \times 10^{-6}$ ohm-cm.
 - (2) Good adhesion to base material.
 - (3) Free from degrading intermetallic compounds.
 - (4) Low ohmic contact to other contacting conductor materials.
 - (5) Amenable to practical production methods for deposition and delineation.

BIBLIOGRAPHY NOTES, Page 17

- (6) Resistant to current-induced electron migration.
- (7) Resistant to electro-chemical corrosion.

b. Resistance after air bake.

- (1) Cr-Au good with ratios less than 1:10 except on silicon (diffuses into silicon)
- (2) Mo-Au and W-Au were best on 450°C air bake, followed by Al and Ti-Pt-Au.

c. Current density test (needed for specifying conductors).

- (1) Titanium and Cr best at
 $I = 1 \text{ A/cm}^2$.

d. Electrochemical corrosion test.

- (1) Mo-Au and Cr-Au opened.
- (2) Following best after 3 hours,

Ti-Pt-Au	Zr-Au
Ti-Pt	Nb-Au
Ti-Rh	Ta-Au
Hf-Au	Ni-Au
Ti-Au	Co-Au

- e. As a result of the tests, it was concluded that combinations of Ti-Pt-Au, W-Au, Ni-Au, and Ta-Au gave best results.

40. Photolithographic Processing as Related to Beam Leaded Integrated Circuit Technology, NEPCON, 1970, R.W. Hodgson, WE.

A description is given of photoresist processing materials and techniques. These materials include purified KMER, AZ 1350H, KTFR.

41. A Survey of the Major Chip Interconnection Techniques, NEPCON, 1970, Howard K. Dicken, Integrated Circuit Engineering Corporation.

Discusses problems related to multiple bonding and associated material aspects. Data is given which shows that chips degrade rapidly at temperatures above 300°C. As an example, β drops by a factor of 2 after 6 hours at 250°C. The conclusion was that needed were (1) ultrasonic ball bonding (2) monolithic chips eliminate interconnections and (3) beam leaded devices.

42. Application of Polyimide Film (Kapton) in Low-Cost Chip Packaging and Hybrid Semiconductor Memories, NEPCON, 1970, K.C. Hu, Hughes.

The physical and electrical properties of Kapton are listed. The main undesirable feature is that it is somewhat hygroscopic.

43. Designing Inductors for Thin-Film Applications, Electronic Design, February 17, 1964, H.G. Dill, Hughes

The article points out that the design of thin-film inductors is limited by inherent low inductance values, low Q and undesirable coupling effects. Design equations are given and theoretical and experimental data are presented together with improved methods to minimize the undesirable effects.

Some points to be considered are:

- a. L is maximum for round coil forms, decreasing with square and rectangular forms in that order.

b. Measured Q are lower than actual Q's because:

- (1) Resistivity of the deposited conductor is increased because of the rough surface compared to the thickness.
- (2) Skin effect
- (3) Strong electric field along the edges of the spiral.

c. The ratio of the outer diameter to the inner diameter for optimum Q is 5.

44. Lumped Elements in Microwave Integrated Circuits, IEEE Transactions on Microwave Theory and Techniques, December, 1967, Daniel A. Daly, et al., RCA

This paper describes the use of lumped elements for microwave integrated circuits up to 2.5GHz in order to reduce circuit dimensions. Inductors and capacitors have been built with Q's greater than 50 at lower S-band. Amplifier has gain of 4.7db at 2GHz which is about 0.5db less than unit with distributed matching networks using microstrip.

a. Inductors.

- (1) Q is improved by increasing conductor width; limited by self resonance resulting from parasitic interturn capacitance.
- (2) Circular spirals have higher Q's than square ones.
- (3) Varying conductor thickness from 10 microns to 4 mils produced essentially no change in Q. It is concluded that two or three skin depths is an upper useful thickness.

- (4) Inductor Q increases with frequency with the rate of increase approximating the expected square root of frequency dependency.

b. Capacitors

- (1) Capacitors, using a dielectric of SiO_2 formed by controlled oxidation of silane, have Q of 40-60 from 0.5 - 2.5GHz. Q's of 100 at 2GHz were quoted from Texas Instruments for thin-film capacitors using reactively sputtered SiO_2 .

- 45. Rigid and Nonrigid Beam Lead Substrates, ISSCC, 1970, F.J. Brachner et al., MIT Lincoln Laboratory.

Substrates (rigid and nonrigid) are formed with openings and beam leads for mounting integrated circuits. Rigid beam-lead substrates use glass, silicon or alumina. Nonrigid substrates are implemented with a polyimide material.

- 46. Transistors, Diodes and Components, BSTJ, May-June, 1970, A.J. Wahl et al.

This article described techniques used for screening devices and components for extremely high reliability applications.

- a. Semiconductor devices are aged 24 weeks with checks at approximately 4-week intervals.
- b. Resistors (above 5 ohms in value) are formed from tantalum-nitride films, reactively sputtered and

anodized, 5-10 ohms per square, on sapphire substrates. Resistors are aged for 4000 hours at 0.25 watt and 25°C. Some units were aged up to 2000 hours. Critical units were aged 4000 hours, measured and examined for whisker growth, and then aged 250 hours at 0.5 watt and 25°C. These units were then re-examined and measured for electrical requirements. After aging, resistors were selected for assembly by utilizing fixed and variable limits.

- c. Solid tantalum capacitors were aged at 35 volts and 85°C for six months. Capacitance, dissipation factor and leakage current were monitored. Any significant deviation from normal was cause for rejection.

d. Results

- (1) Common emitter current gain change of 0.002 per transistor over 20 years had 0 - 0.0017 percent failures per 1000 hours.
- (2) Resistors (90% confidence) had 0.0000024 percent failures per 1000 hours.

BIBLIOGRAPHY NOTES, Page 22

47. Hybrid Integrated Microwave Amplifier, IEEE MTT Transactions, September, 1968, Caulton et al.

Measurements were made on inductor coils. Conductor material was about 10 microns copper covered with 1 micron gold. Substrate material was sapphire.

Turns	d _o	W mils	S	d _i	L nH	0.5GHz	Q 1GHz	2GHz
2.5	48	4	2	12	(c) 4.5	81	115	162
					(m) 4.4	53	61	100 ₊₂₀
2.5	49	5	1	11	(c) 4.3	97	137	194
					(m) 4.4	52	72	120 ₊₂₅
3.0	32	2.5	1	10	(c) 4.8	67		
					(m) 4.6	36		

(c) Calculated

(m) Measured

APPENDIX B
QUALITY, RELIABILITY AND DESIGN STANDARDS
FOR MICROWAVE HYBRID MICROCIRCUITS

B-1

1. SCOPE

1.1 Purpose - This standard establishes the controls which shall be implemented in the design and fabrication of *microwave* hybrid microcircuits for use in high reliability space applications. These controls encompass; design requirements; documentation, as concerns processes, drawings, and specifications; selection of parts, materials, and processes; and quality assurance requirements.

1.2 Application - This standard is not intended to be used for procurement of "off-the-shelf" hardware - selected portions may however be referenced, i.e.: screening requirements to assure the acquisition of a reliable device. The intended use of this standard is for the procurement of custom packaged, low volume type, *microwave* hybrid microcircuits.

1.3 Design Standards - Included, as an Appendix A to this document, are recommended design standards which should be considered in the manufacture of *microwave* hybrid microcircuits.

2. REFERENCE DOCUMENTS

2.1 The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on the date of invitation for bids or request for proposals shall apply:

DRAWINGS

George C. Marshall Space Flight Center

85M03878	Test Standards for Microcircuits
85M03916	Packaging, Packing and Shipping Requirements for Electronic Parts, Standard For

STANDARDS

Military

MIL-STD-883 Test Methods and Procedures
for Microelectronics

MIL-STD-1276 Leads, Weldable, For Electronic
 Component Parts

George C. Marshall Space Flight Center

MSFC-STD-355 Radiographic Inspection of Electronic Parts, Standard For

Other

EIA Standard for Film Networks

SPECIFICATIONS

Federal

Solder, Tin Alloy; Lead Tin Alloy;
and Lead Alloy

QQ-S-571

George C. Marshall Space Flight Center

85M03927 "Carrier Mounted" Chip Devices,
Specification For

85M03926 *Design and Quality Standards
for Custom Hybrid Microcircuits*

3. REQUIREMENTS

3.1 Performance - *Microwave* hybrid microcircuits supplied to this document shall meet all of the requirements specified herein and in the individual procurement specifications.

3.1.1 Manufacturer's Responsibility - Manufacturers supplying *microwave* hybrid microcircuits fabricated to the requirements of this specification are obligated to assure the cognizant NASA procuring activity that these *microwave* hybrid microcircuits meet the minimum requirements of this specification. If, at any time, there is a question as to the ability of a *microwave* hybrid microcircuit to perform as required, the manufacturer shall inform the procuring activity.

3.2 Precedence - In the event of conflicts or inconsistencies in any of the applicable documents, such documents, shall rank in the following order of precedence:

- (a) Individual Procurement Specifications
- (b) This document
- (c) MSFC documents specified in 2.1
- (d) Other documents specified in 2.1

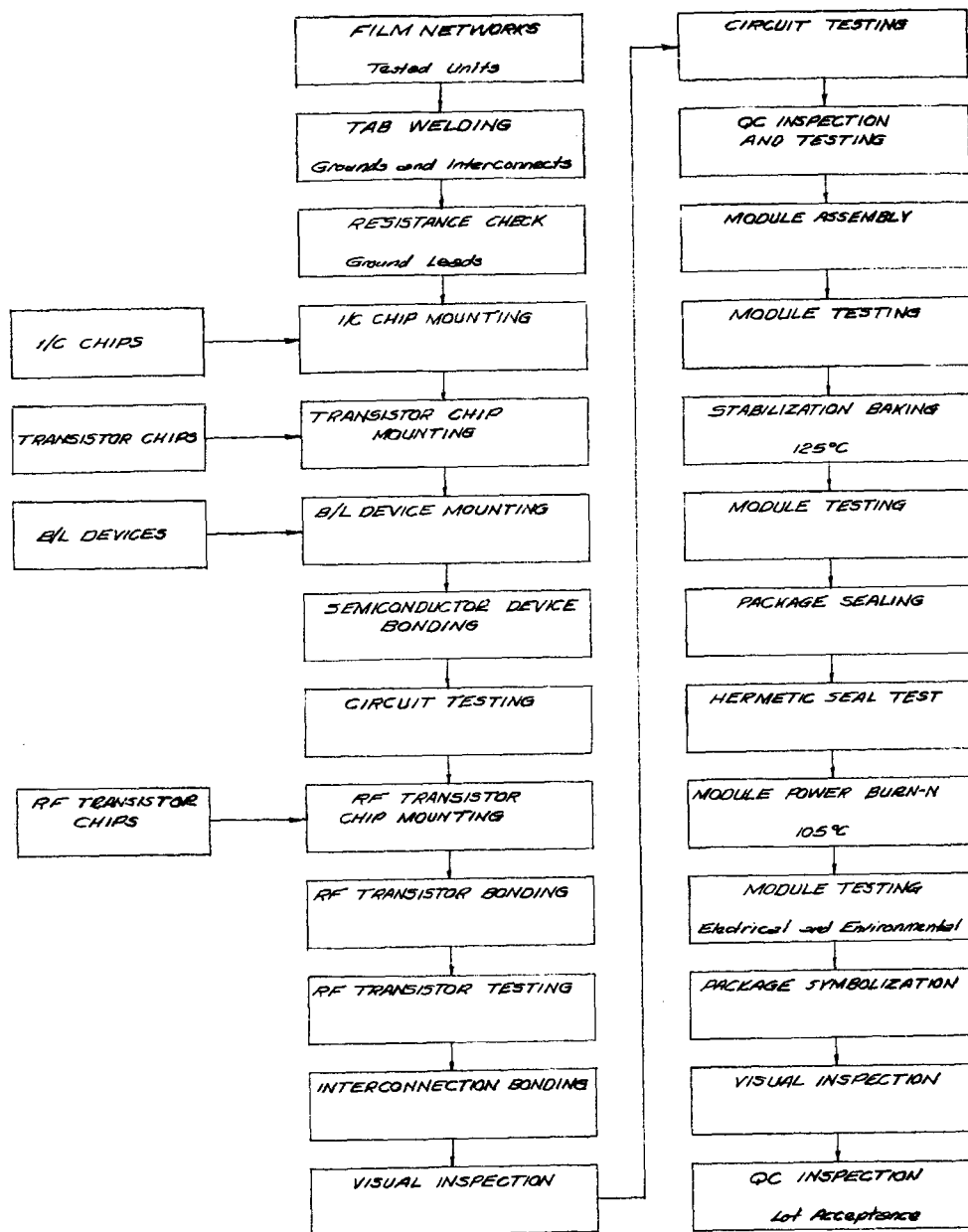
3.3 Electrical - The electrical requirements shall be as specified in the individual procurement specification. In the event of conflict between this document and the individual procurement specifications, the latter shall take precedence.

3.4 Mechanical - The *microwave* hybrid microcircuit mechanical requirements shall be as specified in the individual procurement specifications. These requirements shall be consistent with the dimensional inspection criteria specified in the *microwave* hybrid microcircuit Appendix herein. In the event of conflict between this document and the individual procurement specifications, the latter shall take precedence.

3.5 Interchangeability - All *microwave* hybrid microcircuits having the same procuring activity part number shall be directly and completely interchangeable with each other with regard to installation and performance within the requirements of this document and the individual procurement specification.

3.6 Documentation - The documentation requirements including latest revisions, for *microwave* hybrid microcircuits procured to this specification shall be specified herein.

3.6.1 Process Control - The flow charts shown in Figures 1 and 2 depict the typical stages of design, fabrication and test required for supplying *microwave* hybrid microcircuits procured to this specification. The *microwave* hybrid microcircuit supplier shall submit a similar flow diagram which will include any of the additional manufacturing stages which are peculiar to this process. A list of the manufacturing documents, including number and revision date, associated with each of the stages shall be submitted. This documentation shall relate to the processes and controls concerning, but not limited to, the preparation, fabrication, inspection criteria, quality control points, bond strength tests, equipment calibration, test parameters and procedures. This documentation shall, upon request, be made available to the cognizant NASA procuring activity for evaluation. The *microwave* hybrid microcircuit suppliers may submit alternate or an existing process flow diagram, which he feels is adequate, to the procuring activity for review and necessary approval. The supplier shall also submit documentation which will reflect the justification for each of the proposed flow chart deviations.



Typical Microwave Hybrid
Microcircuit Assembly Flow Chart

Figure 2

3.6.2 Drawings - The manufacturer shall provide the necessary drawings which will adequately detail the electrical and mechanical characteristics of the *microwave* hybrid microcircuits procured to this specification. These drawings shall include, but not be limited to the following:

- (a) Assembly drawings
- (b) Schematics
- (c) Wiring diagrams
- (d) Parts Lists

3.6.3 Proprietary Processes, Drawings and Procedures - Proprietary processes, drawings and procedures shall be completely documented with name, number, release date, and latest revision date. Documents describing proprietary processes need not be submitted to the procuring activity; but upon specific request of the activity the supplier shall demonstrate to the procuring activity that the proprietary operations are completely defined and that proper controls are specified.

3.6.4 Procurement Specification - The *microwave* hybrid microcircuit manufacturer shall generate the individual part specifications which in conjunction with the MSFC Drawing 85M03927 comprises the documentation necessary to procure chip devices. The individual parts specification shall be submitted in writing to the cognizant NASA procuring activity for review and approval. The cognizant NASA procuring activity will reply within two (2) weeks. No reply within this time will be construed as approval and procurement may proceed.

3.7 Parts, Material, and Processes - Parts, materials and processes shall comply with the requirements specified in the individual procurement specifications in addition to the requirements specified herein.

3.7.1 Compatibility - Parts, materials and processes used in the manufacture of *microwave* hybrid microcircuits shall be compatible in the environmental conditions specified in the individual procurement specifications.

3.7.2 Packaging - Each *microwave* hybrid microcircuit shall be packaged in accordance with the requirements specified herein.

3.7.2.1 Hermetic Seal - Each *microwave* hybrid microcircuit shall be hermetically sealed and shall comply with the hermetic seal requirements specified herein.

3.7.2.1.1 Solder Glass Seals - The use of solder (lead) glass as a hermetic sealing compound shall not be permitted.

3.7.2.1.2 Plastics - The use of resin embedment or plastic encapsulation for the purpose of obtaining a hermetic seal shall not be permitted.

3.7.2.2 Outgassing - When applicable, the outgassing requirements for the material used for coating and marking of the hermetically sealed *microwave* hybrid microcircuits shall be as specified in the *microwave* hybrid microcircuit procurement specification.

3.7.2.3 Package Leads - Package leads shall meet one of the following requirements: (*This provision shall not apply to RF screw-on or plug-in type connectors.*)

3.7.2.3.1 Soldered - The external leads of the package, when dipped in non-corrosive flux followed by a dip tin in a solder pot containing 63/37 tin-lead solder in accordance with specification QQ-S-571 at a temperature of $260^{\circ} \pm 15^{\circ}\text{C}$ with a dwell time of not greater than 5 seconds, shall be capable of retaining not less than 95 percent of the solder.

3.7.2.3.2 Welded - The external package leads shall be type "K" material per MIL-STD-1276. The extent to which MIL-STD-1276 is imposed is to ensure the composition of the lead material.

3.7.3 Chip Devices - The requirements for the active and passive chip devices, to be mounted within the microwave hybrid microcircuit, shall be as specified herein.

3.7.3.1 "Carrier Mounted" Chip Devices - The use of chip devices which are not located on a carrier (minor substrate), prior to be mounted on the major hybrid substrate, shall be permitted only as specified below.

3.7.3.1.1 For the purpose of this requirement "leadless" passive chip devices such as ceramic monolithic capacitors and deposited film resistors, capacitors and inductors shall be considered as "carrier" mounted chip devices.

3.7.3.1.2 Circuit Substrates with directly mounted chip and beam lead devices shall be subjected to a 240-hour power burn-in at maximum rated power input and temperature in a controlled inert atmosphere oven. After burn-in, the circuits shall be electrically re-tested to specified parameter limits and visually checked to the normal inspection criteria prior to mounting in the circuit module.

3.7.3.2 Mounting - The "carrier mounted" chip devices shall be mounted to the major substrate by means of plastic, solder or eutectic mounting techniques which are consistent with the inspection criteria specified herein.

3.7.3.2.1 Plastic - When plastic is used, it shall meet the following requirements: It must not contain amines or material which form acids or hydroxides with or without water absorption. It must be compatible with aluminum, gold and all of the precious metals, all cermet materials, alumina, glass beryllia, copper, kovar, and nickel. The plastic material shall have an operating temperature rating of 200°C minimum. Insulative plastic must have a minimum resistance of 10^{12} ohm-cm at 200°C. The plastic shall have a good bond strength consistent with the mechanical environmental requirements. *Data must be available to verify that the material meets the above requirements or specific tests must be conducted to verify the suitability of the material for a particular application.*

3.7.3.3 "Flip Chips" - The use of "flip chip" devices shall not be permitted. Deviations to this requirement, with the justification, may be submitted to the cognizant NASA procuring activity for consideration and necessary approval.

3.7.3.4 Storage - Chip devices not involved in processing for periods in excess of eight (8) hours shall be stored in a dehumidified chamber and inert atmosphere comparable to dry nitrogen.

3.7.4 Substrates - Substrates for microwave hybrid microcircuits shall be compatible with the materials, processes and discrete elements used in the fabrication of the microcircuit. Selection of substrate material shall consider electrical requirements and environmental conditions. High purity alumina ceramics and sapphire are recommended for general microwave use. Fused silica (quartz), rutile, and ferrite ceramics are used in special applications. Glazed ceramics and general purpose alumina ceramics are not recommended for microwave transmission lines.

3.7.4.1 Surface Finish for Microwave Circuitry - The surface finish of a glazed substrate or the glazed portion of a selectively glazed substrate shall not exceed a roughness of 1 microinch CLA. The surface finish of high purity alumina substrates in an as-fired condition shall not exceed a roughness of 10 micro-inches CLA.

3.7.4.2 Surface Finish for Non-Microwave Thick Film Circuitry - The substrate finish shall not exceed a roughness of 40 microinches CLA.

3.7.4.3 Dielectric Constant - The dielectric constant (ϵ_r) of the microwave substrate material shall be within $\pm 2\%$ of the specified design value. A typical value of ϵ_r is 9.6 ± 0.2 for high purity alumina ceramics.

3.7.4.4 Dielectric Loss - The loss factor ($\tan \delta$) for low dielectric constant materials ($\epsilon_r < 10$) shall be a minimum of 0.0002 at frequencies below 10 GHz. The loss factor for ferrites and rutile (TiO_2 ceramic) shall be a maximum of 0.002 below 10 GHz.

3.7.4.5 Thickness - The thickness of a microwave circuit substrate shall not vary more than $\pm 7\%$ from the design value.

3.7.4.6 Purity - The purity of alumina and beryllia ceramics for microwave applications shall be 99.5% minimum.

3.7.5 Screen Printing, Vacuum Deposition, and Trimming - The processes used in the screen printing, vacuum deposition and film trimming of conductors and/or passive elements on the major substrate shall result in a finished product that conforms with the requirements specified herein.

3.7.5.1 Circuit Element Spacing - The spacing between circuit elements shall be as specified in Table I.

Table I. Minimum Design Spacing Requirements

Circuit Elements	MINIMUM SPACING REQUIREMENTS (Inches) *		
	Photo Etch** or Photo Plate	Deposited	Screened Printed
Conductor - Conductor	0.0025	0.005	0.010
Conductor - Resistor	0.003	0.005	0.010
Resistor - Resistor	0.002	0.010	0.010

* Increase the minimum spacing in increments of 0.001 inch for each 25 volt increase above 50 volts (50 to 75 volts, 75 to 100 volts, etc.)

** The minimum spacing for edge-type microwave couplers shall be 0.0005" minimum.

3.7.5.2 Conductor Width - The minimum design conductor line width shall be as specified in Table II.

Table II Minimum Design Conductor Line Widths (Inches)

Vacuum Deposited		Screen Printed
Subtractive	Additive	
0.0025*	0.004	0.010

*The minimum line width for high impedance chokes and transmission lines shall be 0.001".

3.7.5.3 Resistors

3.7.5.3.1 Segment Length - The minimum and maximum resistor segment length of vacuum deposited and screen printed-resistors shall be as specified in Table III.

Table III Acceptable Resistor Segment Length

Type	Length (Inch)	
	Minimum	Maximum
Additive	0.015	0.500
Subtractive	0.010	None
Screen Printed	0.025	None

3.7.5.3.2 Width - The minimum design width for subtractive, additive, and screen printed resistors shall be 0.0025, 0.003, and 0.010 inch respectively.

3.7.5.4 Capacitors - The configuration of vacuum deposited or screen printed capacitors shall be in accordance with the dimensions specified in Figures 3 and 4. Microwave capacitors formed by vacuum deposition, selective etching and selective plating are shown in Figures 5 and 6.

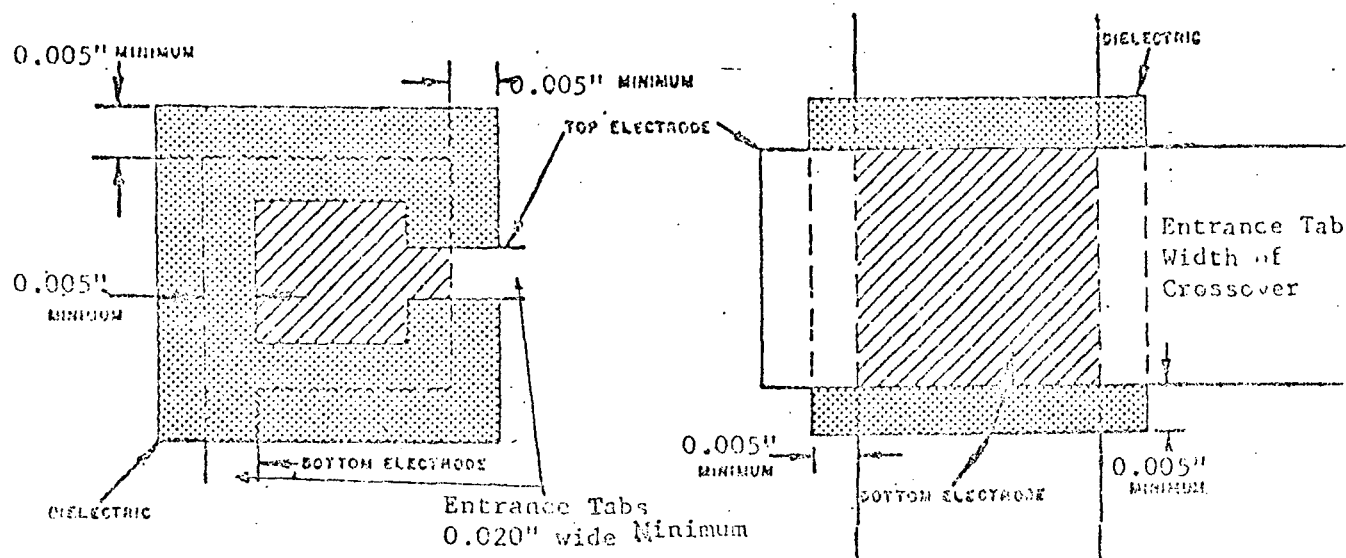


Figure 3. Capacitor Configuration (Vacuum Deposited)

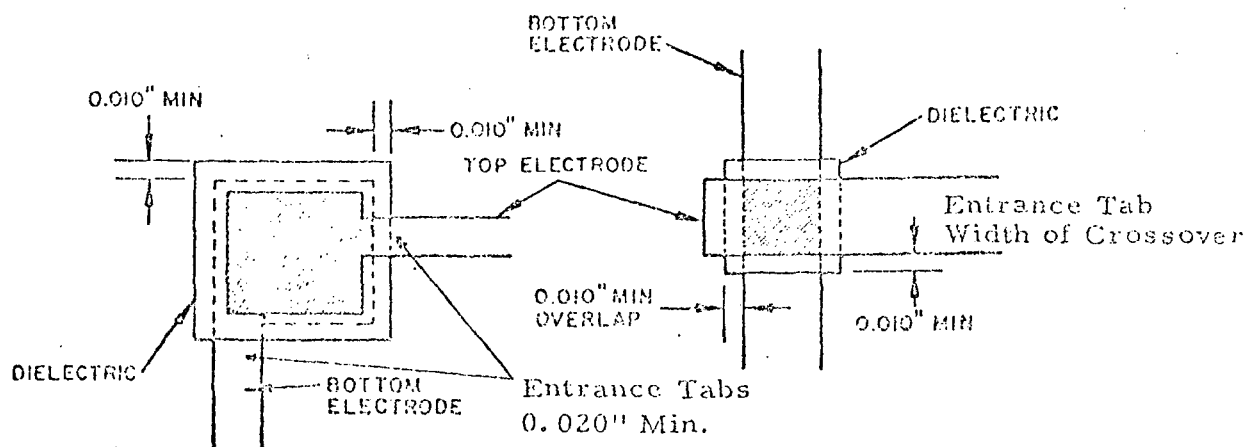


Figure 4. Capacitor Configuration (Screen Printed)

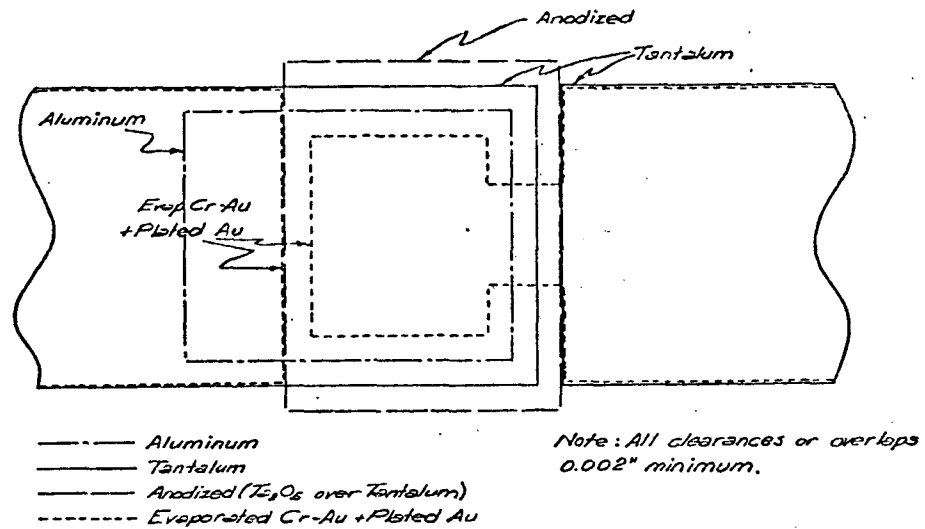


Figure 5. Microwave Thin Film Capacitor
 (Ta_2O_5 Dielectric)

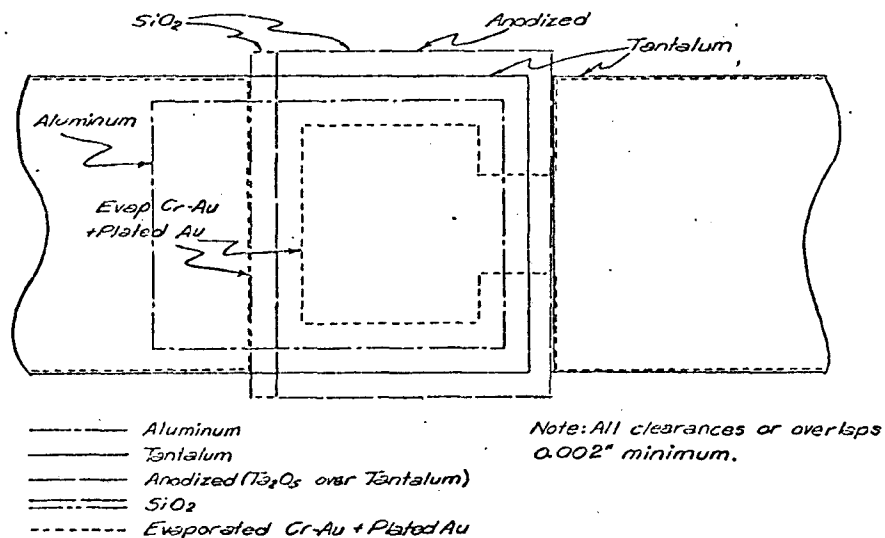


Figure 6. Microwave Thin Film Capacitor
 (Ta_2O_5 & SiO_2 Dielectric)

3.7.6 Wiring, Internal - The internal wiring of the hybrid microcircuit shall be in accordance with the requirements specified herein.

3.7.6.1 Conductor Bonds - Inter or intra connections within the hybrid microcircuit shall be accomplished by thermo-compression, ultrasonic, or parallel gap bonding techniques using gold or aluminum wire *or strap* . Solder connections are not permitted. All bonds, prior to sealing of the hybrid microcircuits, shall be visible and in accordance with the acceptance criteria specified herein. *Sample bond pull tests shall be made prior to each production lot or each shift if lot assembly extends over more than one shift.*

Pull strength values for sample bond pull tests shall not be less than those listed in Table IV.

Table IV. Minimum Bond Pull Strength (Grams)

Dimension (Inches)	Minimum Pull Strength
0.0005 diameter	1
0.0007 diameter	2
0.001 diameter	4
0.0005 x 0.005	14
0.0005 x 0.010	29
0.0005 x 0.020	58

3.7.6.2 Conductor Length - Conductor material used for interconnections shall not exceed the maximum length specified in Table V.

Table V. Maximum Conductor Lengths (Inches)

<i>Conductor Dimensions</i>	<i>Maximum Length</i>
<i>0.0005 diameter</i>	<i>0.070</i>
<i>0.0007 diameter</i>	<i>0.085</i>
<i>0.001 diameter</i>	<i>0.100</i>
<i>0.002 diameter</i>	<i>0.125</i>
<i>0.003 diameter</i>	<i>0.150</i>
<i>0.0005 x 0.005</i>	<i>0.100</i>
<i>0.0005 x 0.010</i>	<i>0.100</i>
<i>0.0005 x 0.020</i>	<i>0.100</i>

3.8 Marking - The markings on each hybrid microcircuit shall be capable of withstanding, without becoming illegible, all the environmental tests and conditions specified herein. The following information shall be permanently and legibly marked on each microcircuit:

- (a) Part number
- (b) Manufacturer's identification (name, symbol, or trademark)
- (c) Serial number
- (d) Date code

The identification marking shall be located so that it will be visible for inspection when the microcircuit is installed.

3.8.1 Part number - After successful completion of the appropriate screening requirements listed in Section 4.0, the hybrid microcircuit shall be marked with its appropriate part number.

3.8.2 Serial number - Serialization shall be numerical or alphabetical numerical at the manufacturer's option. No two hybrid microcircuits with the same part number and having a date code of the same year shall have the same serial number. Positive identification of each hybrid microcircuit shall be maintained throughout all testing.

3.8.3 Date code - All hybrid microcircuits shall be marked with the week of sealing identified by a four digit numerical date code. Reading from left to right, or top to bottom, the code shall consist of the following digits:

- (a) First and second digits - The last two digits of the year.
- (b) Third and fourth digits - The calendar week of sealing. (Use zero for the third digit for weeks one through nine.)

3.9 Storage of Parts Prior to Sealing - Parts shall be protected in an inert environment to ensure that environmental conditions will not have a detrimental effect on the functional operation or cause subsequent aging of the part characteristics.

3.10 Repair and rework - Repair and rework of *microwave* hybrid microcircuits at any stage of fabrication shall not be implemented without prior approval of the cognizant NASA procuring activity. If rework procedures are anticipated, applicable flow diagrams showing rework paths, allowable degree of rework cycling, quality standards for re-inspection, and detailed rework procedures shall be submitted to the cognizant NASA procuring activity with a request for approval.

3.11 Deviations - Deviations from the requirements of this standard shall be approved in writing by the cognizant NASA procuring activity prior to implementation.

3.12 Surveillance - The procuring activity retains the right to assign designated representatives to the supplier's plant to perform surveillance functions in connection with *microwave* hybrid microcircuits furnished under this standard.

4. QUALITY AND RELIABILITY ASSURANCE PROVISIONS

4.1 General - It shall be the manufacturer's responsibility to employ sufficient controls, examinations, measurements, and tests to ensure that each *microwave* hybrid microcircuit supplied to this specification is free from defects, capable of performing in full accordance with the end-item or *microwave* hybrid microcircuit specification and adequate for use in high reliability space applications.

4.2 Chip Devices (Active and Passive) - Chip devices, prior to mounting on the *microwave* hybrid microcircuit major substrate, shall have been tested in accordance with the individual parts specification and MSFC Drawing 85M03927.

4.3 Classification of Examination and Test - The inspection and testing of hybrid microcircuits covered by this specification shall be classified as follows:

(a) Qualifications

(b) Screening

4.3.1 Qualification - Unless otherwise specified, only the qualification of the end-item (i.e. *transceiver*), which houses the *microwave* hybrid microcircuit device(s), shall be necessary and the qualification requirements shall be as specified in the end-item procurement specification. In the case where only the un-installed hybrids are separately procured against this standard, the qualification requirements (sample size, disposal, grouping, tests and criteria) shall be as specified in the hybrid microcircuit procurement specification.

4.3.2 Screening - Each *microwave* hybrid microcircuit shall be screened in accordance with the requirements specified herein.

4.3.3 Microwave Hybrid Microcircuit - Each completed *microwave* hybrid microcircuit delivered to this specification shall as a minimum, have successfully completed all the examinations, tests and measurements in Appendix B.

4.3.4 Test Conditions - Unless otherwise specified, all visual examinations and tests shall be performed at room temperature (17°C to 28°C) and a relative humidity of less than 50 percent.

4.3.5 Changes in screening tests - The manufacturer shall be responsible for notifying the cognizant NASA procuring activity of any screening tests that, in the manufacturer's opinion, do not effectively detect failures or could create new failures. When these conditions are substantiated by the manufacturer the screening tests in question may be changed at the option of the procuring activity.

4.3.6 Test Data - One copy of all recorded test data and one set of the applicable radiographs shall be packaged with each shipment of *microwave* hybrid microcircuits. In addition, and when applicable, as stated in paragraph 20.3.2 of Appendix B one copy of all recorded tests data and the explanation and justification for parameter selection and limits established shall be submitted to the cognizant NASA procuring activity. If the procuring activity is MSFC the address for submission of data is as follows:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812
Attention: S&E-QUAL-FP

5. PREPARATION FOR DELIVERY

5.1 Packaging

5.1.1 When this standard is used for the procurement of discrete uninstalled *microwave* hybrid microcircuits (i.e. spares), the hybrids shall be packaged, packed, and the package marked in accordance with MSFC Drawing 85M03916.

5.1.2 When the *microwave* hybrid microcircuits are procured as part of an end-item (i.e. computer) the preparation for delivery shall be specified in the end-item procurement specified in the end-item procurement specification.

6. NOTES

6.1 Definitions of Terms

Active Part or Element - Providing amplification or control to a voltage or current in an electrical circuit (opposite of passive), e.g., transistors, diodes.

Additive - The process of applying thin film pattern formations to a substrate through masks by vacuum deposition.

Adhesion - The act or state of sticking or being united and attached to.

Angstrom (Å) - A unit of measurement. One angstrom is equal to approximately 1/250 millionth of an inch (1×10^{-7} mm).

Ball Bond - A thermocompression bond in which the ball shaped end of a gold wire is bonded to an aluminum pad. Also referred to as "nail head bond."

Beam Leaded Chip Devices - Chips formed with large, heavy leads extending over the chip edge.

Bubble - An air or gas pocket enclosed in a vitreous material, e.g., substrate glass.

Bump Contacts - A small amount of material formed on the chip substrate to register with terminal pads, as when the chip is employed in "flip-chip circuits."

Ceramic - A product composed of inorganic non-metallic compounds formed through heat processing, e.g., alumina.

Chip - An unpackaged die, originally part of a wafer, that contains one or more active or passive elements.

Circuit - The interconnected combination of a number of elements or parts to accomplish a desired electrical function.

Contamination - The presence of undesirable foreign material such as dust, moisture, brush fibers, fingerprints, etc.

Crack - A partial separation of a device or substrate without an actual opening.

Crossover - A method used to connect two circuit elements by depositing an intraconnection material over the insulated upper surface of another circuit element or interconnect.

Curling - The lifting and rolling back of the edges of the deposited film from the substrate material.

Deformation - A condition that describes the deformed appearance of a bonded wire or bump contacts of a semiconductor device.

Delamination - A separation of layers, e.g., a separation or opening between capacitor plates.

Deposited Substrate - A substrate material upon which has been deposited a thin or thick film microcircuit array.

Deposition - The process of applying a material to a substrate by means of electromechanical, screening, or vacuum methods.

Device - A combination of physical materials forming an active part comprised of one or more active or passive elements, e.g., transistor, diode, integrated circuit.

Die - An alternate term for "chip".

Dielectric - An insulating material, such as silicon monoxide, used in microelectronic devices to fabricate capacitors and to insulate conductors.

Discrete Part - A separately packaged single circuit element supplying one fundamental property as a lumped characteristic in a given application. e.g., resistor, transistors, diode.

Dynamometer - A force indicating gage used to measure shear or tensile values of a bonded wire or chip device.

Element (of a microcircuit or integrated circuit). A constituent of the microcircuit or integrated circuit that contributes directly to its operation. (A discrete part incorporated into a microcircuit becomes an element of the microcircuit.)

Evaporative Material - The material which is to be or has been deposited on a substrate. It is also referred to as deposition material.

Evaporative Deposition - The technique of condensing a film of evaporated material upon a substrate. (Also called vacuum deposition.)

Film Microcircuit - A microcircuit whose elements are film formed in place upon an insulating substrate by screen printing or vacuum deposition.

Flip-Chip - A hybrid circuit made by merging monolithic-silicon and film techniques. Monolithic chips are flipped over to be bonded face down to the conductive film pads. See "bump contacts."

Fracture - The start or beginning of a crack, stress lines

Gouge - A groove, e.g., a deep scratch.

Header - The portion of a device package from which external leads extend, e.g., metal container.

Hybrid Microcircuit - A microcircuit fabricated on an insulating substrate utilizing some combination of monolithic chip, and/or thick-and thin-film components, and/or discrete parts.

Inclusion - Foreign material embedded in or below the surface of another material.

Integrated circuit. A microcircuit consisting of interconnected elements inseparably associated and formed in situ on or within a single substrate to perform an electronic circuit function.

Interconnections - The joining of one individual device with another.

Intraconnections - The joining of elements within a device.

Metallization - The deposition of a metal film on a substrate or device by evaporative deposition, vapor plating, etc.

Microelectronics - That area of electronic technology associated with or applied to the realization of electronic systems from extremely small electronic parts or elements.

Microcircuit - A combination of intra-connected elements on a single substrate or a combination of intra-connected elements and parts on or within a substrate to perform an electronic circuit function.

Micron - A unit of length equal to 1×10^{-6} meter.

MIL - A term meaning one thousandth of an inch (0.001).

Monolithic Circuit - A circuit that is fabricated within a single block of material.

Multichip microcircuit - A microcircuit consisting of elements formed on or within two or more semiconductor chips which are separately attached to a substrate.

Network (thick or thin film) - A portion of a substrate upon which passive elements such as conductors, resistors and capacitors have been formed and upon which active and/or passive elements will be mounted to form a complete electronic circuit element.

Overcoat - A thin film of material, usually silicon monoxide, applied over deposited circuit elements for the purpose of mechanical protection.

Pads - Metalized terminal areas on the surface of a chip or on a passive substrate as integral portions of the conductive interconnection pattern to which bonds, interconnections, or test probes may be applied.

Parallel Gap Bonding - A method of resistance welding in which both electrode tips are in close proximity to each other, being separated by a small gap, and approach the work from the same direction.

Part - One piece, or two or more pieces joined together, which is not normally subject to disassembly without destruction of designed use, e.g., composition resistor, transistor, substrate with printed resistors.

Passivation - The surface treatment of a semiconductor material to protect the device from the effects of moisture and contaminants, e.g. oxidation, glazing, etc.

Passive Part of Element - Does not provide amplification or control to a voltage or current in an electrical circuit, e.g., capacitors, resistors.

Pattern Definition - The accuracy of the reproduction of pattern edge in the elements of a deposited thin-film circuit, e.g., the absence of shading.

Peeling Circuitry - See curling

Pin Hole - A very small hole extending through a layer of material. Normally used to describe small holes in a layer of silicon monoxide (SiO) or other dielectric material of a device or deposited substrate.

Pig Tail - A term that describes the amount of excess wire that remains at a bond site beyond the deformed wire end. Excessive pig tail usually refers to remnant wire in excess of three wire diameters.

Pit - Small holes or depressions in the surface of a material which does not extend through the material.

Protrusions - Small portions of material that extend out from a given point or surface.

Purple Plague - An expansive gold-aluminum inter-metallic which often forms at an interface of a gold-aluminum thermocompression bond. This inter-metallic appears purple in color in the crystalline form.

Reticle - A system of lines in the focus of the eyepiece of a microscope used to measure dimensional characteristics.

Screen Printing - The process of applying through a screen thick film patterns formations to a substrate.

Selective Plating - The process of plating through a photoresist mask to form the conductive portion of a circuit network.

Semiconductor Carrier - A special part that is used as a mounting base for semiconductor chips.

SiO Coating - A dielectric material used in the surface passivation of microelectronics circuits.

Sattered Material - An undesirable condition where very small pieces of the evaporative material during vacuum deposition are expelled from the crucible and adhere to the substrate and physically interfere with the deposited circuit elements.

Stitch Bond - A thermocompression bonding technique which is essentially a combination of the ball and wedge bonding concept. Since a ball formation is not required to form a bond, aluminum or gold wire may be used.

Striae - An undesirable condition which may be present in substrate or optical glass. Consisting of streaks, veins, or layers of glass of slightly different composition within the glass itself.

Substrate - The supporting material upon or within which the elements of a circuit are fabricated or attached.

(a) Minor - The material upon or within which chip devices are fabricated, such as semiconductors, resistors, capacitors, etc.

(b) Major - The assembly upon which the minor substrates are mounted, in addition to screened or deposited devices or intraconnects.

Subtractive Etch - The process of forming film circuits by etching the desired pattern in the pre-deposited layers using photographic masks and photoresist.

Thick Film Network - An electronic circuit or collection of electronic components which have been formed on a passive substrate by means of "silk screening" of viscous liquid compounds of metals, metal oxides, binders and various glasses and subsequently fired at elevated temperatures. The term is used synonymously with "Screened and Fired" circuits.

Thin Film Network - An electronic circuit or collection of electronic components which have been formed on a passive substrate by means of vacuum evaporation, sputtering, plating and/or pyrolytic deposition of a wide variety of materials.

Thermocompression Bonding - The joining of material by the combining forces of heat and pressure, i.e., ball bonding, wedge bonding, stitch bonding.

Thru-Mask Deposition - The process of forming thin film circuits by interposing a mask or "stencil" between the substrate and the vapor source. The pattern of holes in the mask defines the final deposit pattern. Masks are generally fabricated from thin sheets of metal, graphite or glass.

Topology - The surface layout of the elements comprising an integrated circuit.

Ultrasonic Bonding - The connection of a wire lead or bump contact to a termination point using ultrasonic vibrations. This technique is sometimes referred to as scrubbed bonding.

Wafer - A thin slice with parallel faces of an active substrate such as silicon. The wafer is separated after processing into chips containing individual circuits.

6.2 Ordering Data - Procurement documents shall specify the following.

- (a) NASA part number
- (b) Title, number, and latest revision of this specification
- (c) Title, number, and latest revision of the latest detail specification
- (d) Level of control required, i.e., level 1,2,3 or 4.

NOTICE: When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any right or permission to manufacturer, use or sell any patented invention that may in any way be related thereto.

Custodian:

NASA - George C. Marshall
Space Flight Center

Preparing Activity:

George C. Marshall Space
Flight Center

APPENDIX A
RECOMMENDED DESIGN STANDARDS
FOR
CUSTOM MICROWAVE HYBRID MICROCIRCUITS

10. SCOPE

10.1 This appendix establishes the recommended design standards for custom *microwave* hybrid microcircuits. The cognizant NASA procuring activity shall be notified in writing of all deviations, with justifications, from these recommended design standards.

20. RECOMMENDED DESIGN STANDARDS

20.1 General Topography

20.1.1 Film Layout - Preferred design layout for all resistors, capacitor plates, dielectrics and conductors shall be parallel to the edges of the substrate as shown in Figure A-1.

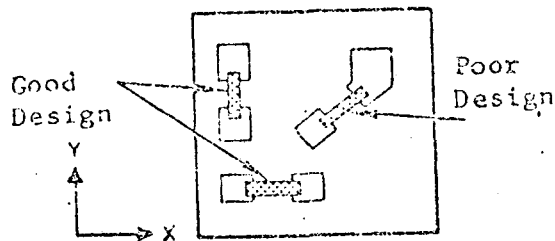


Figure A-1. Film Layout

20.1.2 Crossovers - Conductors and resistor crossovers shall be avoided whenever design conditions permit. If design constraints are such that crossovers must be used, the crossover shall be accomplished by either jumper wires (*straps*) or film conductors. An insulating

dielectric film of sufficient thickness and width shall be deposited at the point of film crossover to prevent shorting of the crossover to the element being traversed. See Figure A-2.

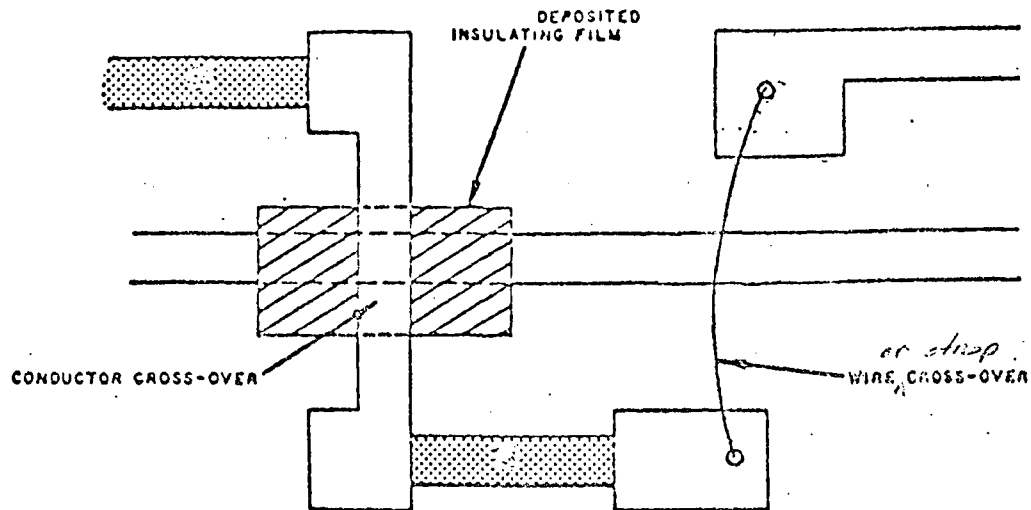


Figure A-2. Crossovers

20.1.3 Pattern Delineation Processes

20.1.3.1 Thin Film - There are *three* methods of pattern delineation in the preparation of the thin film *microwave* hybrid micro-circuits. The circuits can be made by the "subtractive" (photo-etching) process, by the "additive" (masking) process or by the "selective plating" (photo-plating) process. Each of the methods has certain advantages. The primary advantage of the masking process is the fact that it is a dry process without the use of chemicals. The photoetching process gives better resolution and improves process speed. The photo-plating process approaches the resolution and process capability of the photoetching process. Moreover, it allows the formation of thick conductors (typically 10 microns) necessary for microwave transmission line with maximum economy. The design steps involved in all methods and the recommendations for eliminating possible design problems that may be encountered in each method are as follows:

20.1.3.1.1 Subtractive - The subtractive process involves the vacuum deposition of the resistive and conductive film layers on the substrate. The conductor and resistor circuit patterns are then formed by the photo-etch removal of unwanted film.

NOTE

The conventional method of etching the thin film resistor patterns, see Figure A-3, top, create weak points at the junction where the resistor and conductor films meet (Figure A-4). The etching method illustrated in Figure A-5 is preferred. This preferred method will eliminate weak points and permit a higher density of resistor design.

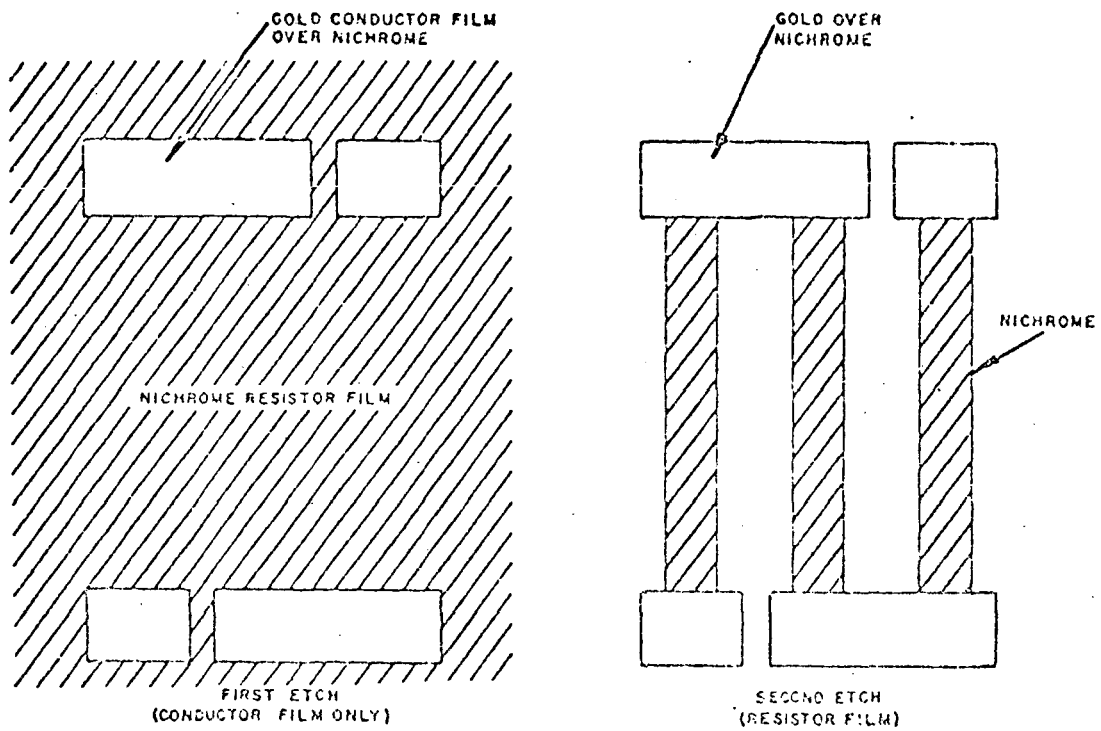


Figure A-3. Conventional Method (Not Recommended)

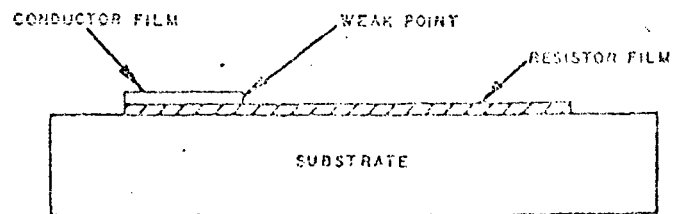


Figure A-4. Resistor - Conductor Junction

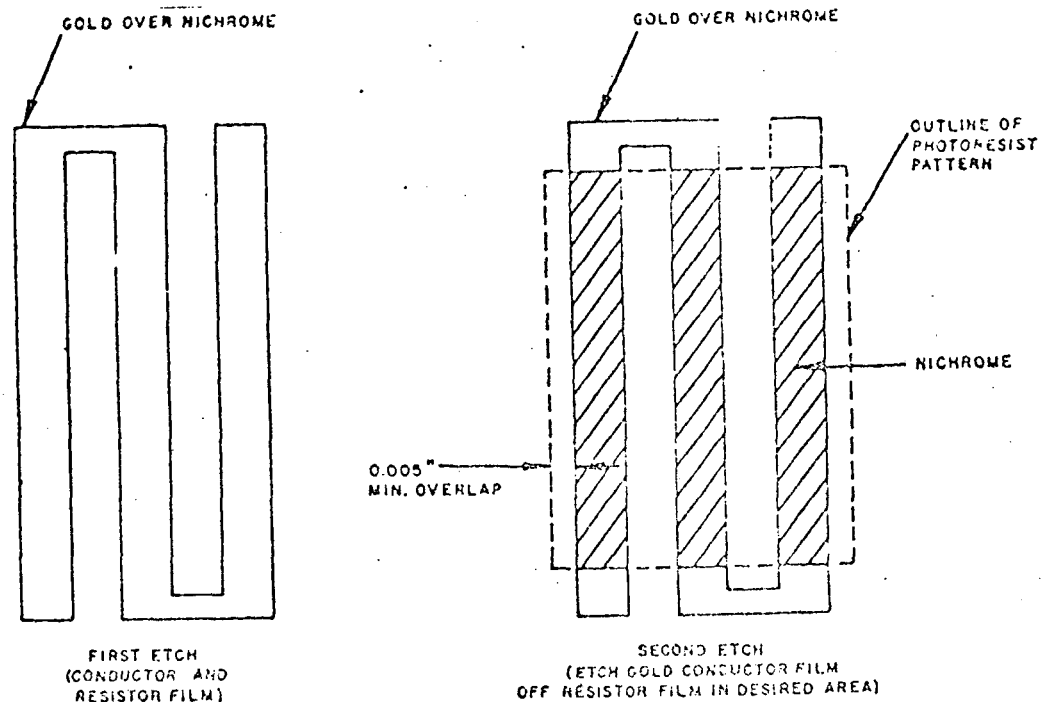


Figure A-5. Recommended Method

20.1.3.1.2 Additive - The additive process involves vacuum deposition of successive thin-film layers through metal masks. The vapor stream travels through the mask openings and impinges on the substrate where it adheres in the desired pattern. The masks should be fairly simple. For complicated high density patterns it is better to use two separate masks. Avoid patterns having numerous turns and bends on one mask as these unsupported portions of the mask cannot be held tightly against the substrate. *The use of magnetic masks and small castellated magnets to hold the mask against the substrate will improve the delineation for complex patterns.*

20.1.3.1.2.1 Deposition Sequence - The recommended film deposition sequence is depicted in Figure A-6. The resistor film should be deposited first; this will result in the elimination of weak points which might exist where a 100-150 angstrom resistor film crosses over a 2000-5000 angstrom conductor film.

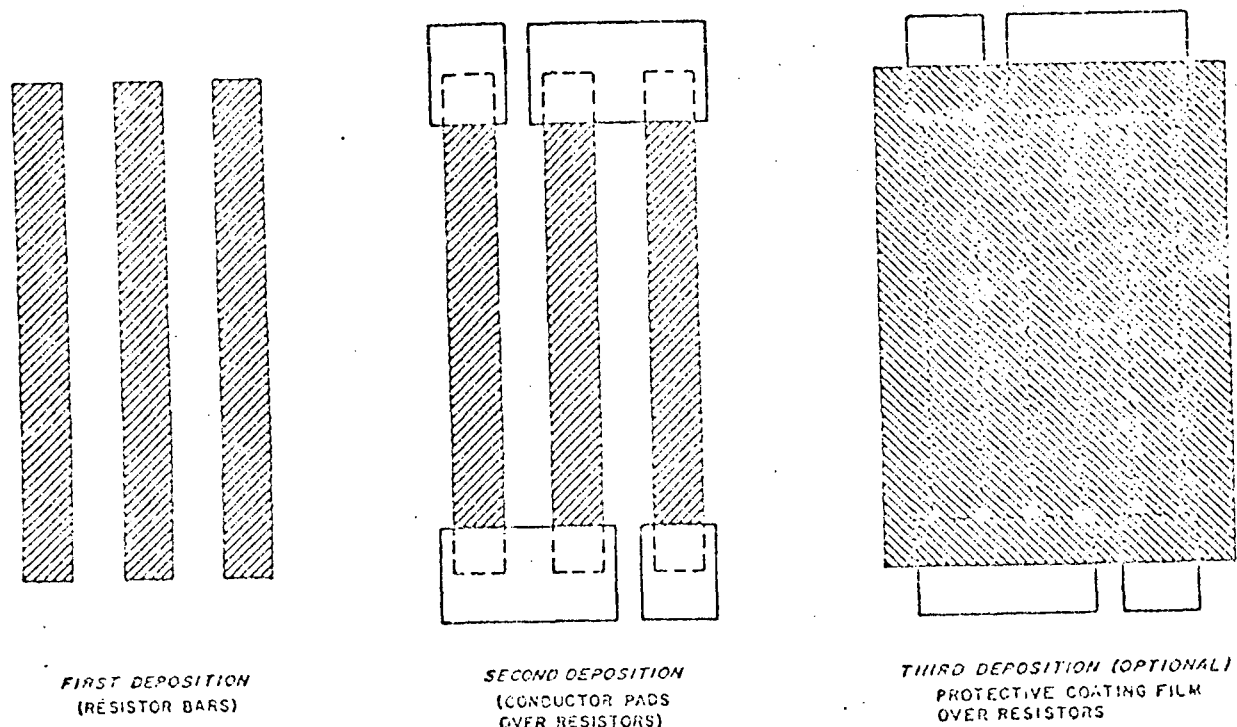


Figure A-6. Vacuum Deposition Through Metal Masks

20.1.3.1.3 Selective Plating - The selective plating process involves vacuum deposition of a thin film of the conductor material. A photomask is placed on the circuit and the conductor pattern is electroplated to the desired thickness. The thin layer of evaporated material is removed by etching, leaving the plated conductor pattern.

20.1.3.2 Thick Film - In thick film technology the screen printing technique is used to apply conductor, resistor and dielectric film patterns to the substrate.

20.1.3.2.1 Screen Printing - Circuit patterns are generated on the screen by the use of a development process (direct emulsion or transfer blocking method) which leaves clear areas on the screen through which the film (ink) can be deposited on the substrate. The circuit elements are produced on the substrate when ink is forced through the clear areas of the screen by use of a blade or squeegee. Stainless

steel wire mesh printing screens are recommended because of their durability and non-absorbent characteristics. Printing screens of 100 to 325 mesh are suitable for circuit printing. The 325 mesh screen is preferred for fine line definitions and the 100 mesh screen is preferred for maximum uniformity of the applied composition. *Microwave transmission often require better definition than can be achieved by screen printing. To attain more accurated patterns the relatively thick film of gold or silver can be fired on the substrate and subsequently photoetched.*

20.1.3.2.2 Deposition Sequence - Conductor inks should be screened and fired prior to resistor deposition as the higher firing temperature of the conductor would damage the resistors. Conductor inks which fire in the same range as the resistor inks are available, however, co-firing results in a decrease of conductor film adhesion properties and is not recommended.

20.2 Substrate

20.2.1 Geometry - In general, substrates (*networks*) shall be of a rectangular or square configuration compatible with the chosen package (*module*) configuration.

20.2.2 Holes - *Where possible, substrates shall be of a homogeneous and continuous construction. If it is necessary to form holes through the substrate for plated-through ground connections or other purposes, the hole centers should not be located closer than 0.070" to each other, nor closer than 0.050" to the edge of the substrate (network).*

20.3 Conductor Requirements -

20.3.1 Material - Gold or other materials such as copper and silver which have been overplated with gold are preferred materials for use as microwave conductors. The material should have a high electrical conductivity and be suitable for bonding operations. The bulk resistivity of the conductor material should be less than 10×10^{-6} ohm-cm.

20.3.2 Conductor Length - DC conductors will be as short as possible within topography and design constraints to minimize circuit resistance. Microwave conductors used as distributed circuit elements shall be optimized for electrical performance.

20.3.3 Conductor Thickness - Conductor films shall be a minimum of two skin depths based on conductor resistivity and circuit operating frequency. In addition, dc conductors will be of sufficient thickness to meet resistivity requirements of less than one-hundredth (0.01) ohms per square.

20.4 Resistor Requirements

20.4.1 Materials - Resistors shall be formed from materials compatible with the other materials used in fabrication of the microwave hybrid microcircuit and consistent with sheet resistivity requirements to attain desired resistance values. In general, screened resistor materials are not suitable for use at microwave frequencies. Thin film resistor materials such as nichrome and tantalum are best suited for this application.

20.4.2 Resistor Geometry - Resistor geometry shall be kept as simple as possible and will be of rectangular configuration whenever design permits. The latter requirement is particularly applicable for microwave resistors. When design parameters are such that the desired resistor value cannot be obtained in a single rectangular configuration, the resistor shall be formed in a zig-zag pattern as shown in Figure A-7.

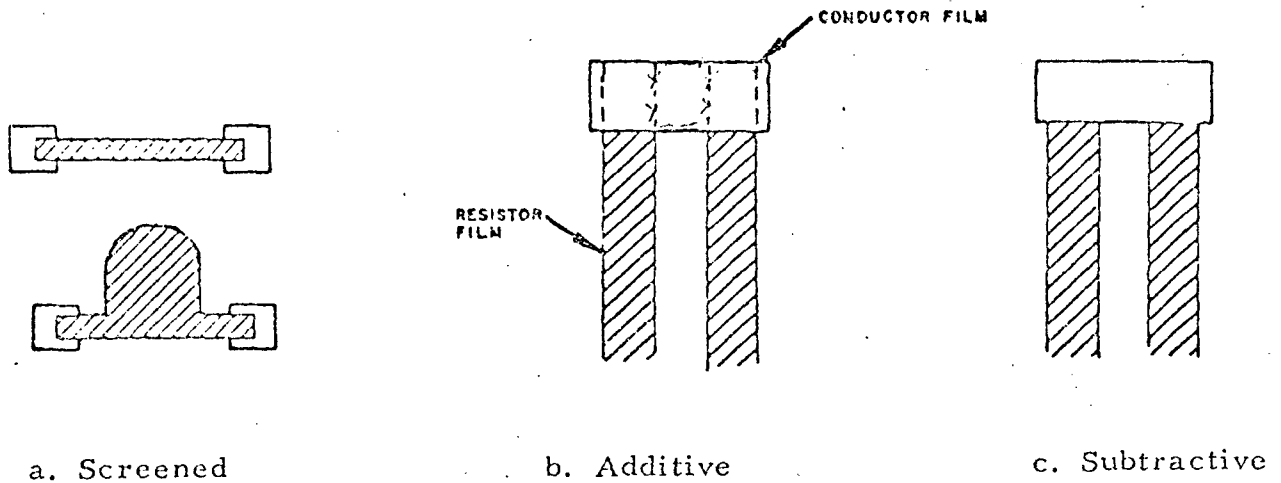


Figure A-7. Film Resistors (Typical)

20.4.3 Resistor Corners - When resistors must be formed in a zig-zag pattern, the pattern corners shall be eliminated whenever possible by deposition of a conductor over the resistor film corners as shown in Figure A-7. In designing the resistor pattern, the effects of multiple "contact resistance" areas at metal-to-metal interfaces should be considered. Also, it is usually not desirable to overlay the pattern corners with conductor material when the resistors are trimmed to value by electrolytic anodization.

20.4.4 Resistor Tolerance and Adjustments - Resistors shall be designed to as large a tolerance and as low a value as possible which is consistent with the functional requirements of the circuit. Resistors shall be trimmed or adjusted as required; the method of trimming shall not degrade the electrical or physical characteristics of the substrate or circuit elements. The trimming process shall not reduce the resistor cross section more than 40 percent.

20.4.5 Discrete Resistors - Resistors in chip form which are compatible with film techniques are available for special applications in hybrid microcircuits. Precautions shall be taken to protect the uncased chips during transportation, handling, inspection and storage to prevent contamination.

20.5 Capacitors Requirements

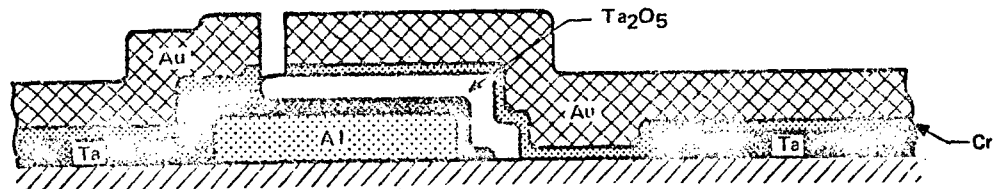


Figure A-7-A. Microwave Capacitor Structure (Typical)

20.5.1 Deposited Capacitors - Capacitors are basically formed as a three layer system as shown in Figure A-8 consisting of a bottom electrode, a dielectric layer, and a top electrode. Whenever possible, deposited capacitors shall be formed in a rectangular pattern. Additionally layers may be included for purposes of providing isolation, layer-to-layer adherence, lower resistivity, etc. A typical microwave capacitor structure is shown in Figure A-7-A.

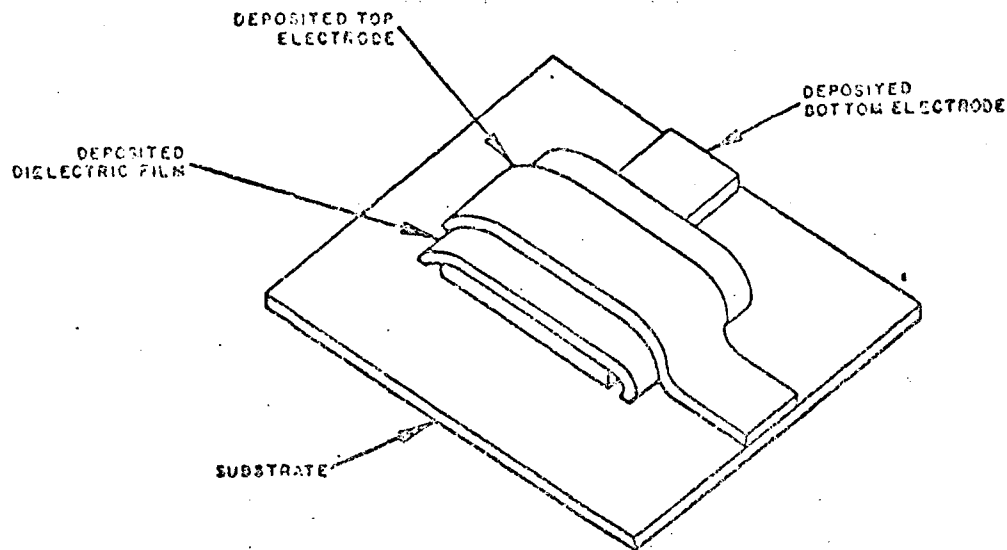


Figure A-8. Capacitor, Three Layer (Typical)

20.5.2 Materials - Capacitor electrodes shall be formed of metals compatible with the other materials and substrate used in the fabrication of the *microwave* hybrid microcircuit. Generally the *top* electrode material shall be the same as the material used for the conductors. The dielectric of the capacitor shall be compatible with the other materials used in the fabrication of the *microwave* hybrid microcircuit and consistent with functional requirements. In particular, the dielectric loss at microwave frequencies must be considered in addition to the dielectric constant and dielectric strength of the dielectric material.

20.5.3 Discrete Capacitors - Capacitors which are compatible with film techniques are available in chip form. The loss factor and/or Q at microwave frequencies must be determined for electrical design purposes. Precautions must be taken to protect the uncased chips during transportation, handling, inspection and storage to prevent contamination.

20.6 Inductors - Inductors in film technology are obtained by producing spiral, linear or tapered conductor patterns (depending on frequency, bandwidth, etc.) on the substrate. The conductor material should have a low specific resistivity (less than 10×10^{-6} ohm-cm) and be at least two skin depths thick at the frequency of interest. Typical inductor design patterns and the characteristics associated with each are shown in Figures to . In general, spiral inductors are useful up to a frequency of about 2 GHz. Linear lines and tapered lines are used at higher frequencies with the latter having the advantage of operating at wider band widths.

20.7 Discrete Circuit Parts - Discrete active and passive circuit parts generally referred to as semiconductor chips, capacitor chips, resistor chips, etc., may be utilized for accomplishing circuit functions. The chip may be mounted to a special intermediate carrier as shown in Figure A-9. The semiconductor carrier assembly requires more area and bonds than the bare chip, but permits electrical testing of the chip after mounting and facilitates replacement of active devices without damage to the film circuitry. The following minimum requirements shall be enforced in the use of chips and carriers.

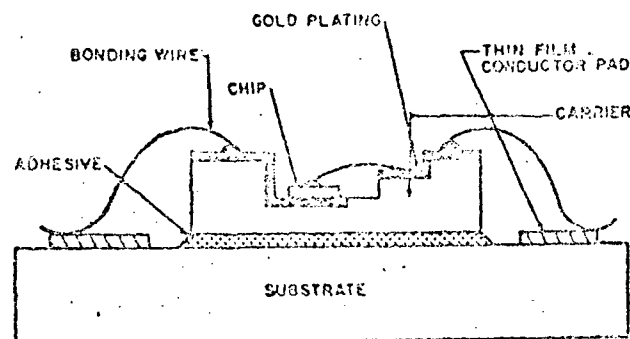


Figure A-9. Semiconductor Carrier (Typical)

20.7.1 Mounting of Semiconductor Carrier - When the semiconductor carrier is mounted on the substrate by use of a solder, organic adhesive or metallic bonding operation, the materials used shall be compatible to the extent that a satisfactory carrier to substrate bond can be achieved.

20.7.2 Mounting Recommendations - If design permits avoid locating semiconductor chips close to the edge of the substrate or mounting discrete components directly across conductor or resistors. If it is necessary to mount components over conductors as a crossover, the component body or conductor must be well insulated. See Figure A-10.

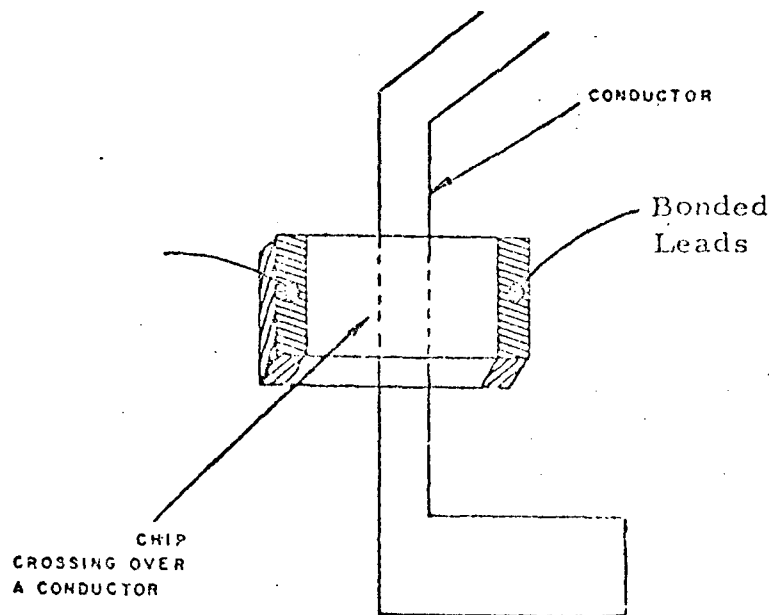


Figure A-10. Crossover Mounting

20.8 Mounting Pads - Most transistor and diode chips are in the order of 0.007" x 0.007" or larger. It is therefore necessary to allow at least 0.005" of pad space greater than the chips dimensions in each direction. See Figure A-11. This should allow adequate contact pad area. If wire bonds are to be made to this same pad, the area must be made correspondingly larger.

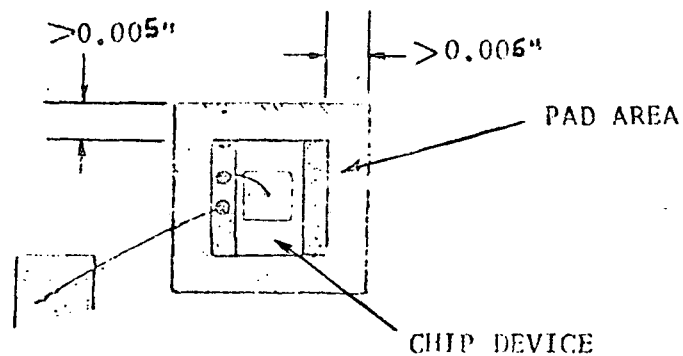


Figure A-11. Mounting Pad Requirements, Typical

20.9 Interconnections - There are numerous semiconductor interconnecting techniques that may be utilized. Each technique has certain advantages and disadvantages, therefore the design engineer must have a thorough working knowledge of each method in order to make optimum utilization of the interconnection method best suited for the particular application.

20.9.1 The interconnection techniques most commonly used and their applicability to the various requirements of microcircuit fabrication may be summarized as follows:

(a) Thermo compression

(1) Ball or nail head bonding

(2) Wedge (*chisel*) bonding

(b) Ultrasonic bonding

(c) Parallel-gap bonding

20.9.2 For connecting semiconductor transistor or integrated circuit chips to the package lead or to a thin metallic film on the ceramic substrate, thermocompression or ultrasonic bonding of gold or aluminum leads is recommended. *For microwave transistors mounted on carriers, parallel gap bonding of gold straps is recommended.*

20.9.3 For interconnections on substrate thin or thick film patterns, thermo compression, ultrasonic or parallel gap bonding is recommended.

20.9.4 For bonding package leads having heavy Kovar or nickel leads to thin or thick film conductors, ultrasonic or parallel gap bonding is most suitable. The various types of interconnections are illustrated in Figure A-12.

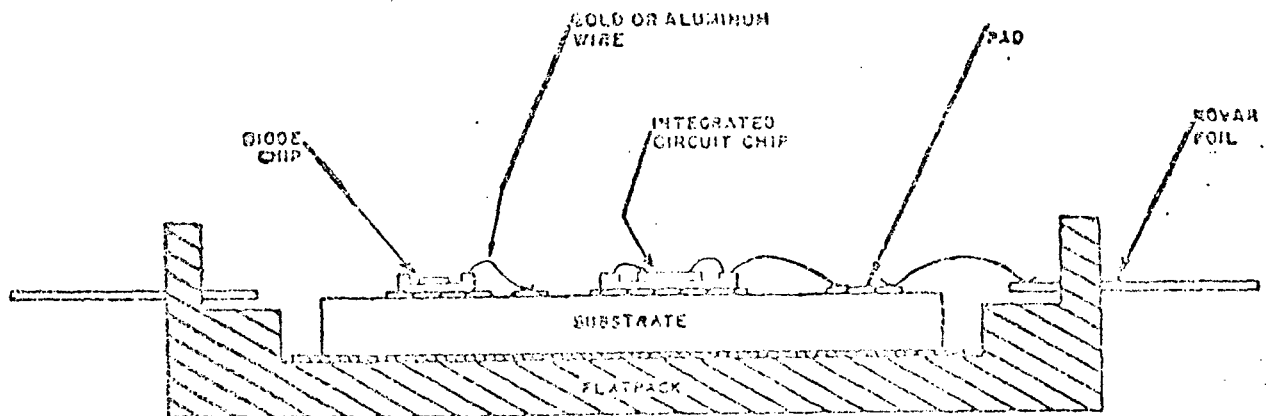


Figure A-12. Interconnections, Typical

20.9.5 Routing - Avoid crossing wire interconnects over another wire or a semiconductor chip. When crossovers are necessary due to desing constraints the number shall be minimized. See Figure A-13.

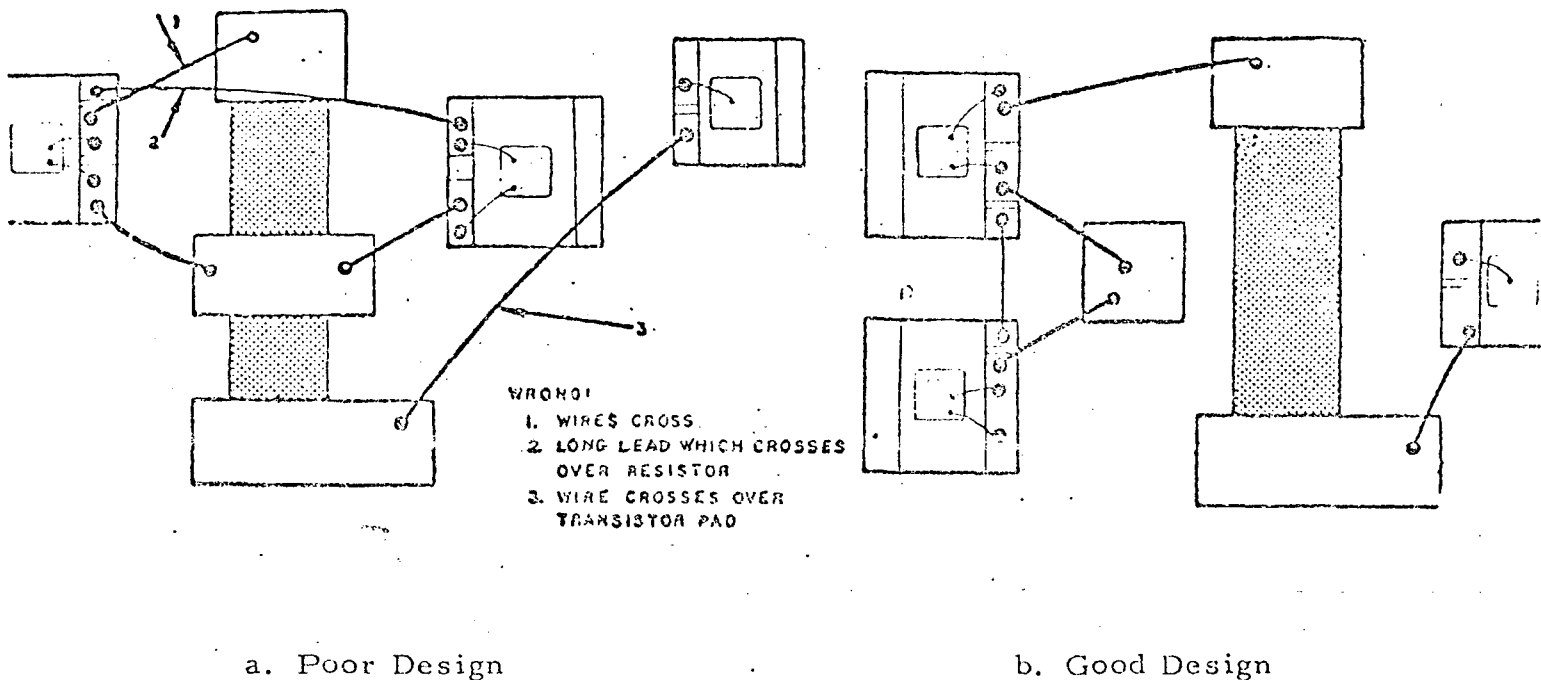


Figure A-13. Interconnection Routing (Typical)

20.9.6 Intermediate Bonding Pads - When interconnects between semiconductor chips are formed by thermocompression, or ultrasonic bonding, interconnects shall not be made directly between the chips but shall be made to intermediate bonding pads as shown in Figure A-13b. Exceptions to this specification with approved bonding procedures must be obtained in cases where electrical requirements require direct interconnects between chips.

20.10 Heat dissipation and transfer problems - The materials utilized in the packages, and the size and configuration of the packages all contribute to the dissipating capabilities of the unit. The internally generated heat is transferred to the outer portion of the unit for dissipation through conduction and radiation. However, the circuit packaging density is rising faster than the power requirements are dropping. This requires increased care during the system design for the dissipation of thermal power. The use of conductive cooling is necessary for vacuum atmosphere and has become a desired requirement for all systems. In order to remove the thermal energy from the external package, conductive cooling is provided on the system board in the form of heat transfer plates. The package is usually attached to the heat transfer plate with a thin bond line of heat conductive adhesive in order to reduce interface thermal resistance. These interface thermal resistance levels must be considered during design in order to provide sufficient area for dissipating heat into the heat transfer plate. This plate is generally attached to the overall system heat sink.

Careful control of the internal thermal design is required to prevent hot spots at the device and component locations. Thermal profiles using infrared photographs should be taken under rf operating conditions to determine peak temperatures across the circuit. In addition, device peak temperatures should be measured using a radiometer with a resolution of approximately 0.001".

APPENDIX B

QUALITY STANDARDS FOR CUSTOM HYBRID MICROCIRCUITS

10. SCOPE

10.1 This appendix establishes the quality standards for custom hybrid microcircuits.

20. Screening - Each hybrid microcircuit shall as a minimum, be subjected to and successfully complete all the examinations, tests, and measurements specified in Table B-1 in the order listed.

Table B-1. Screening

		MIL-STD-883	
Test	Applicable Paragraph	Methods	Conditions
1. Visual Examination, Internal	See 20.1 and 20.1.1	2010	Test Condition C
2. Case Sealing			
3. Manufacturers Process Screening			See Note 1
4. High Temperature Storage		1008	Test Condition C, 48 hours Min.
5. Temperature Cycling		1010	Test Condition C
6. Constant Acceleration	See 20.3	2001	Test Condition B
7. Seal Leak Test, Fine		1014	Test Condition A
8. Seal Leak Gross	See 20.2		
9. Serialization	See 3.8.2		
10. Radiographic			MSFC-STD-355
11. Electrical Measurements EMI	See 20.4		
12. Power Burn-In	See 20.5		
13. Electrical Measurements EM2	See 20.4		
14. Visual Examination, External	See 20.6		

APPENDIX B (Continued)

NOTE: 1. The manufacturer has the option to perform additional post-sealing screening tests and examinations provided they are performed prior to high temperature storage.

20.1 Visual Examination, Pre-Seal - Each *microwave* hybrid microcircuit shall be visually examined in accordance with the inspection criteria specified in method 2010.1, test condition B of MIL-STD-883, exceptions listed below; the requirements of Section 3.0 of this standard, and the additional requirements specified herein. In the event of conflict or inconsistencies the requirements specified herein shall govern.

20.1.1 Exceptions to MIL-STD-883

20.1.1.1 Paragraph 3.2.6.1 (b), last sentence, delete in its entirety.

20.1.1.2 Paragraph 3.2.6 (c), last sentence, delete in its entirety.

20.1.1.3 Paragraph 3.2.7.1, add "*a scratch is defined as any tearing defect that exposes the layer under the metallization at any point*".

20.1.1.4 Paragraph 3.2.7.2, delete in its entirety.

20.1.1.5 Paragraph 3.2.7.4, delete in its entirety.

20.1.2 Magnification Criteria - The magnification criteria for visual examination of hybrid microcircuits shall be as specified in test condition B, method 2010, MIL-STD-883. However, when deemed necessary, maximum magnification requirements may be exceeded to investigate potential failure mechanisms.

20.1.3 Part Mounting Criteria

APPENDIX B (Continued)

20.1.3.1 Eutectic Mount - The eutectic shall exhibit sufficient flow so that it is visible around 75 percent of the mounted chip device. The fillet shall not impinge on any interconnect bonding area. There shall be no extraneous gold on the substrate or upper surface of the chip device resulting from the mounting operation. See Figures B-1 and B-2.

20.1.3.2 Organic Adhesive Mount - The adhesive shall exhibit sufficient flow so that it is visible around 100 percent of the bonded chip device. The fillet shall not extend more than 0.020 inch beyond any edge and shall not overlap or contact any other substrate element or impinge on any interconnect bonding area. Bubbles and/or voids in the adhesive shall not occupy more than 20 percent of the total periphery. There shall be no extraneous organic adhesive material on the substrate or upper surface of the chip device and in addition the organic adhesive material on the substrates or upper surface of the chip device and in addition the organic adhesive material shall not bridge two or more metallizations which are at different potentials. See Figure B-1 and B-2.

20.1.3.3 Solder Mount - The maximum solder flow from the chip device shall not impinge on any interconnect bonding area. The solder fillet shall be visible around 75 percent of the periphery of the chip device. *This provision shall not apply to slug resistors and capacitors. For these units, the requirement shall be 75 percent of the metallized periphery.* There shall be no evidence of cracking or crazing of the carrier or substrate material around the solder edges. The solder shall exhibit a smooth continuous appearance without evidence of brittleness which would indicate poor adhesive qualities. There shall be no extraneous solder on the substrate or upper surface of the chip device. See Figure B-1.

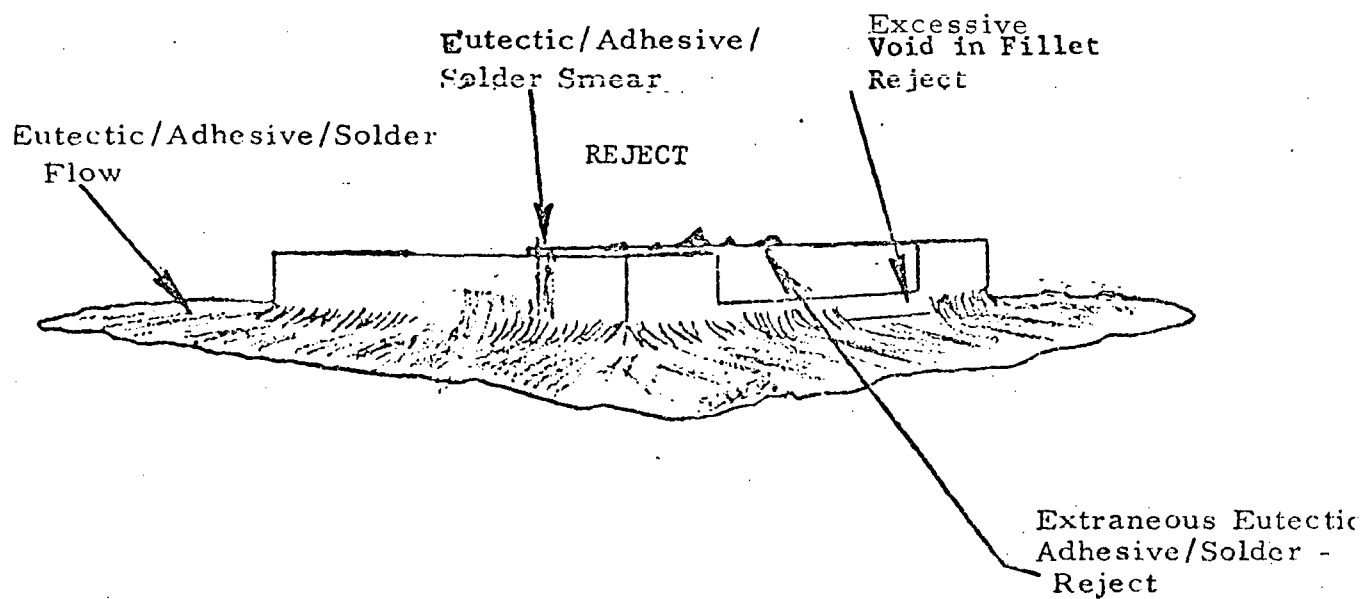


Figure B-1. Organic Adhesive/Eutectic/Solder Mount (Side View)

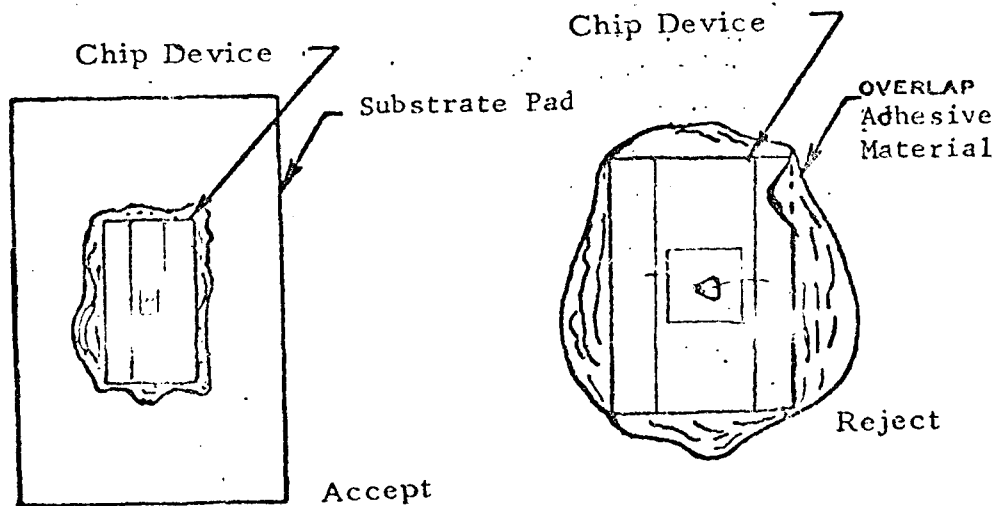


Figure B-2. Organic Adhesive/Eutectic/Solder Mount (Top View)

APPENDIX B (Continued)

20.1.4 Substrate

20.1.4.1 Cracks - A crack in the substrate that exceeds 0.003 inch in length and points toward an active area, metallization or bond, shall be cause for rejection. See figure B-3.

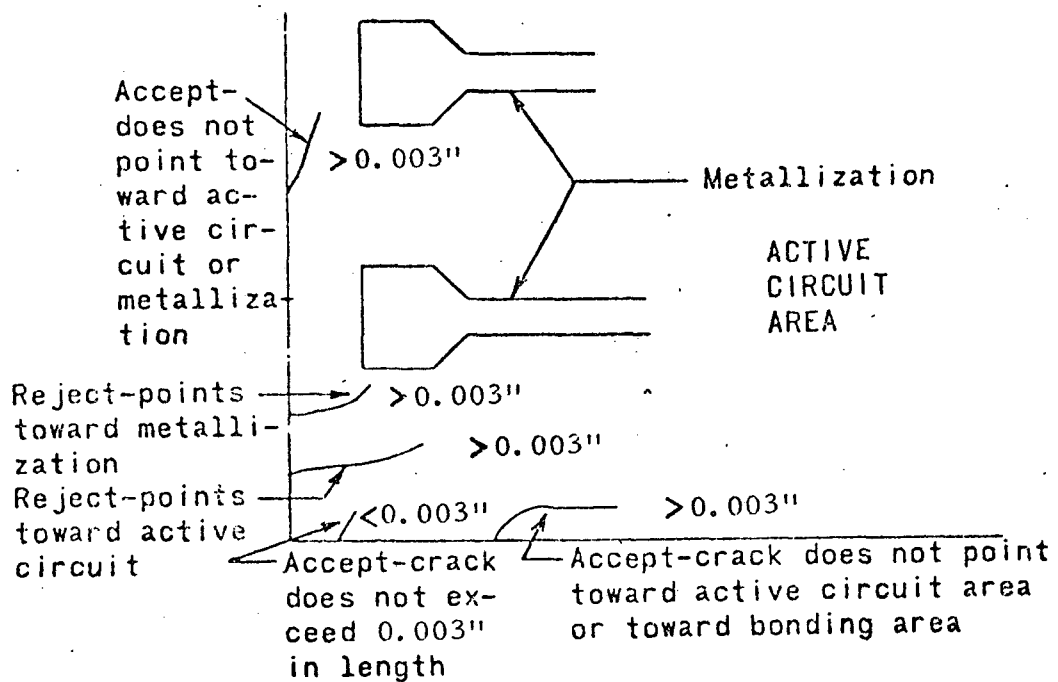


Figure B-3. Substrate Cracks

APPENDIX B (Continued)

20.1.4.2 Spacing Between Metallization and Substrate Edge -

Any microwave hybrid microcircuit which has less than 0.001 inch separation between the metallization and the edge of the substrate shall be rejected. See Figure B-4.

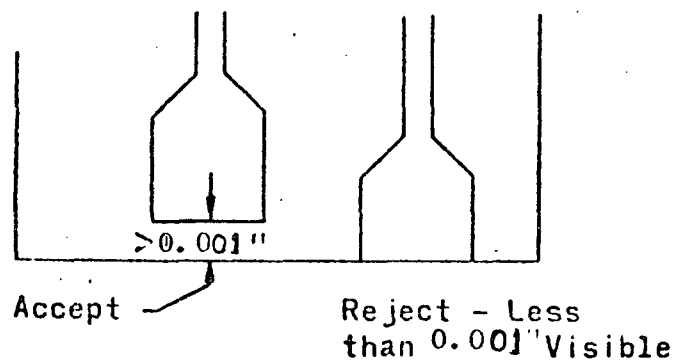


Figure B-4. Metallization/Substrate Edge Spacing

20.1.5 Resistor and/or Conductor film

20.1.5.1 Scratches and/or Voids - Scratches and/or voids that reduce the cross section of the resistor and/or conductor film by more than 25 percent of the design width shall be cause for rejection.

20.1.6 Wire Bonding - The additional inspection criteria for thermocompression, ultrasonic, and parallel gap bonding shall be as specified herein.

APPENDIX B (Continued)

20.1.6.1 Placement - The wire bond shall be placed so that the bonding pad is visible around 75 percent of the circumference of the bond when viewed from directly above the bond. See Figure B-5.

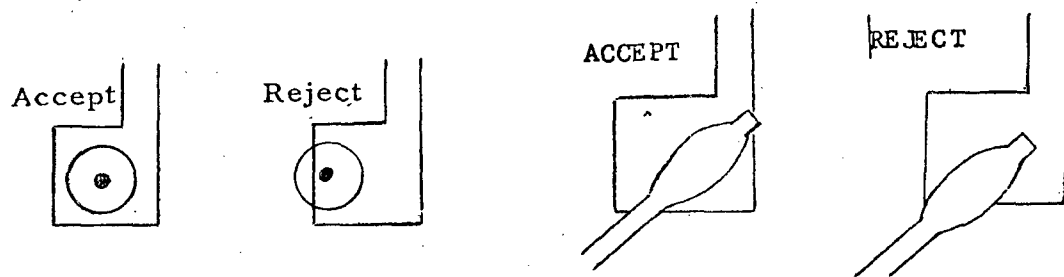


Figure B-5. Wire Bond Placement

20.1.6.2 Pigtail Terminations - Bond pigtail terminations greater than three (3) wire diameters shall be rejected.

20.1.6.3 Wire Stress Bend - There shall be a minimum of three (3) wire diameters of *vertical* wire above the ball bond before bending occurs as shown in Figure B-6.

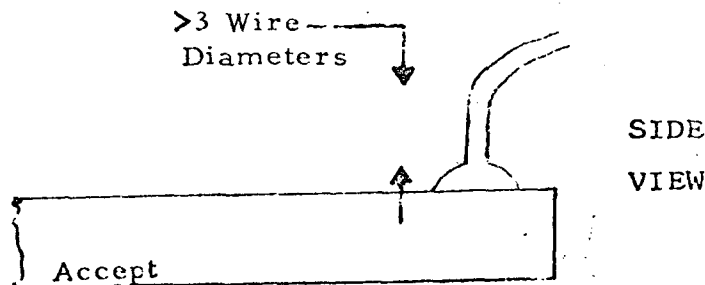


Figure B-6.. Wire Stress Bend

APPENDIX B (Continued)

20.1.6.4 Metal Expulsion - Evidence of metal expulsion in the bonding area shall be cause for rejection. This includes splattering of material from the bonding zone or excessive bulging of the material at the bond interface.

20.1.6.5 Cracks, Pits, Holes or Voids - Any bond where cracks, pits, holes or voids are evident shall be rejected.

20.1.6.6 Discoloration - Burned, intermetallic discoloration or blackened areas in the vicinity of the bond shall be cause for rejection.

20.1.7 Parallel Gap Bonding

20.1.7.1 Width - The width between the inner edges of the bond set down shall be a minimum of $1 \frac{1}{2}$ wire diameters and a maximum of two (2) wire diameters as shown in Figure B-7. *This provision does not apply to "Unitip" bonding.*

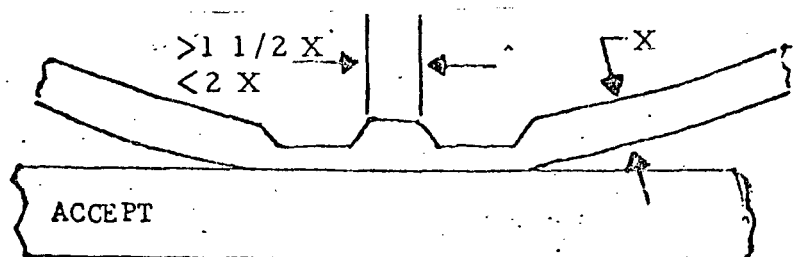


Figure B-7. Width Between Inner Edges

APPENDIX B (Continued)

20.1.7.2 Open Bond - The result of an attempted bond where no fusion or forging action has occurred shall be cause for rejection. See Figure B-8.

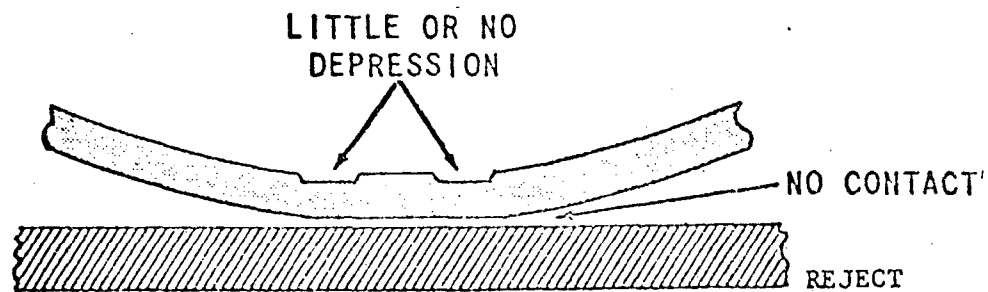


Figure B-8. Open Bond

20.1.7.3 Surface Fusion - Any bond where portions of the materials' that were in contact with the electrodes exhibit melting or fusion shall be rejected.

20.1.7.4. Multiple Bond Attempts - Evidence of multiple bond attempts at the same bond area shall be cause for rejection.

20.1.7.5 Bond Alignment - Incorrect bond alignment such that the electrodes do not maintain contact across the full width of the lead shall be cause for rejection.

APPENDIX B (Continued)

20.1.7.6 Setdown - Any bond that exhibits a setdown greater than *two-thirds* of the wire diameter shall be rejected. See Figure B-9.

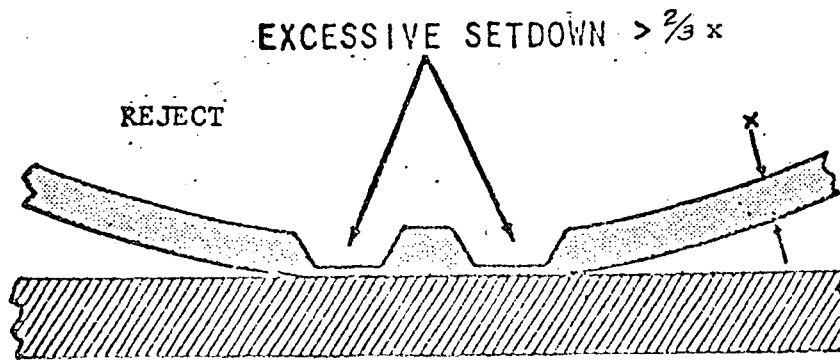


Figure B-9. Setdown

20.2 Seal Leak Gross - Each sealed hybrid microcircuit shall be subjected to one of the following seal leak detection tests.

20.2.1 Flurocarbon - Each sealed hybrid microcircuit device shall be subjected to the flurocarbon gross leak test as specified in step 1, test condition C, method 1014, MIL-STD-883.

20.2.2 Demineralized Water - Each sealed hybrid microcircuit device shall be completely immersed in demineralized water for a period of 3 minutes minimum. The water shall contain no particles greater than 175 microns in any direction and shall have a resistivity of 50,000 ohms minimum. The temperature of the water shall be $90^{\circ}\text{C} \pm 5^{\circ}\text{C}$. Evidence of bubbles shall be cause for rejection of the device.

APPENDIX B (Continued)

20.3 Constant Acceleration - Unless otherwise specified each hybrid microcircuit device shall be subjected to a constant acceleration as specified in Table I, except that the centrifugal acceleration shall be applied to the device in the Y_1 axis only.

20.4 Electrical Measurements - Electrical measurements shall be performed on each hybrid microcircuit as specified herein.

20.4.1 When the individual hybrid microcircuit specifications specifies electrical measurements (EM1 and EM2) as required in the screening table, these measurements will be made in accordance with that specification.

20.4.2 When there are no electrical measurements specified in the individual hybrid microcircuit specification, the manufacturer shall establish and perform sufficient electrical measurements to cover the full range of input and output operating parameters of the hybrid microcircuit device. Insofar as practicable, each individual functional entity shall be tested separately. The manufacturer shall establish and identify to the cognizant NASA procuring activity go-no-go measurements, parameters to be recorded, and parameter delta limits between electrical measurements (EM1 and EM2), for parameters which are sensitive as indicators of dynamic instability degradation, or incipient failures. All delta parameter criteria shall apply between the initial measurement and the present measurement.

20.5 Power Burn-in - Each completed hybrid microcircuit shall be operated for the minimum period of 240 hours at an ambient temperature of $125^{\circ}\text{C} \pm 5^{\circ}\text{C}$ and a supply voltage equal to the operating voltage. All other input and output conditions shall be at the maximum operating values.

APPENDIX B (Continued)

20.6 Visual Examination External - Each sealed hybrid microcircuit shall be examined visually under 4-power minimum magnification after the completion of all specified screening inspections and tests. The examination shall be for quality of workmanship, mechanical soundness, and proper marking. The following shall be rejection criteria:

- a. Improper or cracked seals.
- b. Damaged or improper welds or soldering.
- c. Cracked or scratched coating or plating which exposes base metal.
- d. Bent, twisted, or deformed leads or terminations.
- e. Scratched or erased marking.
- f. Illegible or incomplete markings.

APPENDIX C
DISCUSSION OF SPECIFICATIONS, REVISIONS,
AND ADDITIONS TO MSFC STANDARD 85M03926

C-1

DISCUSSION OF SPECIFICATIONS REVISIONS
AND ADDITIONS TO MSFC STANDARD 85M03926

1. SCOPE

Sections 1.1-1.3 specify adequately the topics covered. Section 1.4 is added to give a specific reference to appendix B, "Quality Standards for Custom Hybrid Microcircuits".

2. REFERENCE DOCUMENTS

2.1 The EIA Standard for Film Networks contains considerable detailed information on process, performance and environmental requirements for film networks. Specifically, the requirement that no more than 50 percent of the width of a resistor shall be removed in a trimming operation should be included in the proposed microwave hybrid microcircuit standard. Any greater reduction in resistor width could lead to excessive localized heating and would also involve a greater probability of mechanical failure. For these reasons, the EIA Standard has been included as a reference document. Suggested revisions to MSFC Specification 85M03927 are included in the narrative report.

Also, MSFC Specification 85M03926 has been added as a reference for this standard since it would be specifically applicable to the low-frequency circuitry of the microwave module.

3. REQUIREMENTS

3.1 Sections 3.1 to 3.5, 3.6.2 to 3.7.2.1.1, 3.7.2.2, 3.7.2.3.1, 3.7.2.3.2, 3.8 to 3.9, 3.1.1 to 5.1.2 do not involve any technical considerations unique to microwave hybrid microcircuits; in addition, they adequately describe the material covered with respect to microwave hybrid microcircuits

and, therefore, have not been altered.

3.6.1 Process Control - The microwave-hybrid-microcircuit flow chart has been shown in two parts, one covering the processing of film conductors, capacitors and/or resistors on the dielectric substrate, and the other showing the assembly of discrete components and active semiconductor devices on the passive network together with the testing of the assembled circuit. This is believed to be a logical break point and reduces the complexity of the flow-chart presentation.

a) Precision Photo Plotter - The precision-photo-plotter step has been added to the mask preparation cycle as an alternative to the use of a coordinatograph master. In addition to reducing the cost and cycle time for preparing photomasks, the precision plotter is operated by computer tape and is therefore much more versatile than other conventional drafting techniques. Diagonal lines, circular patterns and the like can be easily reproduced by the computer-tape method in photomask form. The essential steps in fabricating masks by this method are as follows:

- 1) Prepare a scaled layout of the mask pattern
- 2) Based on the appropriate computer program(s), code the data input and punch the computer card deck.
- 3) Run the computer program to create a plot tape (Calcomp) and prepare an ink plot of the layout
- 4) Check ink plots and correct the computer card deck
- 5) Re-run computer program creating plot (Calcomp) and photomask (Gerber) tapes
- 6) Check ink plots
- 7) Run photomask (Gerber) plots
- 8) Check photomask (Gerber) plots
- 9) Reduce photomask (Gerber) plots to actual scale
- 10) Perform QC inspection

b) Thick Film Processing - The thick-film-processing flow chart has been altered in order to add a photo-etching step. Quite often, the line-width tolerances obtainable by conventional screening and firing techniques are not sufficiently accurate for producing conductors with the required dimensional control for distributed-element transmission lines. The control of line widths can be greatly enhanced by photo-etching the pattern after the conductive material has been formed on the substrate.

An additional factor to be considered in the use of thick-film conductors for microwave applications is the resistivity of the deposited material. The losses in a microwave transmission line, provided the metallization is several skin depths thick, are proportional to the square root of the conductor resistivity. For this reason, conductor inks must be used which approach the conductive properties of the bulk materials (usually gold or silver). The losses in thick-film conductors at microwave frequencies are generally higher than for thin film plated conductors.

c) Thin-Film Processing Subtractive Method - The thin-film process, as applied to the fabrication of thin-film microwave capacitors and resistors on a dielectric substrate and the formation of conductor patterns on the same substrate for transmission lines, distributed tuning elements and interconnects, is somewhat more complex than the process for building low-frequency circuits. For this reason, a detailed description of the process and a brief explanation of the reason for performing each process step is given. A more detailed discussion of the design requirements is presented under the appropriate section, i.e., substrates, conductors, etc.

The substrate material is high-purity (99.5+%) alumina with a surface finish of better than 10 microinches, CLA. The substrate is visually inspected and subjected to a thorough cleaning process. A better quality surface finish is required for forming thin-film capacitors and a selective glaze is placed at the capacitor areas for this purpose.

The glaze is applied in the form of a sodium-free, glass frit mixed with KMER (Kodak Metal Etch Resist). A layer is formed on the substrate using either a spinning or spraying method, as with conventional photoresist material. The pattern is formed by the usual baking, exposing and developing processes leaving the material in the areas where the glaze is desired. The substrate is then subjected to a two-stage furnace process. The first stage drives off the KMER; the second stage fires the glaze pattern.

A layer of aluminum is vacuum-deposited on the substrate and a pattern is formed by photo-etching which leaves aluminum pads in the areas under the microwave thin-film capacitors. The purpose of the aluminum layer is to reduce the capacitor series impedance (normally controlled by the thin unanodized tantalum layer) to a fraction of an ohm, since microwave circuits usually operate at very low impedance levels, typically 50 ohms or less.

A layer of tantalum is sputtered on the substrate to form the base material from which the resistors and capacitors are constructed. A pattern is defined by photo-etching which outlines the conductor, resistor and capacitor areas with breaks at the lines leading to the capacitor top plate.

Through the use of a photoresist mask resistor portions of the circuit pattern are selectively anodized. This operation adjusts resistor elements to the design value and forms a protective layer of tantalum oxide over the resistor material.

Holes are drilled with an air abrasive drill at points in the substrates where ground connections are required. The hole pattern is defined by openings which have been etched in the tantalum film. The ground connections will be formed by similar operations which establish the conductor pattern. It should be noted that ground connections must be made at

specific points in microwave circuit designs.

The capacitor portions of the circuit are selectively anodized to form the capacitor dielectric material. For design purposes, the peak anodization voltage determines the dielectric thickness, corresponding to the desired working voltage, and, consequently, the capacitance per unit area.

A layer of chromium-gold is vacuum-deposited on both sides of the substrate. The thin layer of chromium ($\approx 250 \text{ \AA}$) provides an adherent interface between the gold and the circuit substrate. A photoresist pattern is placed on the circuit side of the substrate (in some instances, a pattern is required on the ground side also) and the substrate is selectively gold-plated to a thickness of approximately 7.5 microns. The capacitor top plates, transmission lines and inter-connections are formed and, also, the ground holes are plated-through in this operation. The photoresist mask is removed and the thin evaporated layers of gold and chromium are removed leaving the desired conductor pattern.

The substrates are visually inspected at this point and subjected to a quality-control inspection in addition to the normal in-line process controls. The capacitors are tested for leakage current at the specified voltage and for capacitance value. The resistors are checked for conformance to the specified tolerance and are adjusted to value if design requirements have dictated the use of a trimmable pattern. Plated-through ground connections are checked for specified maximum resistance value.

The individual circuit networks are separated by diamond sawing or by breaking at scribe lines. Any additional electrical testing such as rechecking of capacitor leakage and measurement and/or adjustment of precision resistors is conducted at this point. The networks are then subjected to a final visual inspection and QC lot-acceptance inspection prior to movement to the circuit assembly area.

d) Circuit Assembly - The first operation consists of welding straps for grounds and interconnections. For some designs, particularly at lower microwave frequencies, some ground connections may be made by welding gold straps over the edge of the substrate. In addition, conductor patterns can be designed with gaps to permit component testing. It is usually desirable to inspect and test ground connections at this point.

The low-frequency portions of a microwave circuit are usually assembled and tested early in the fabrication sequence. Thus, any yield losses at this stage do not involve the more costly microwave semiconductor components. In addition, the assembly of the microwave devices is usually performed at lower substrate temperatures. The diode, transistor and monolithic integrated-circuit chips are mounted on the network by alloying techniques. The beam-lead devices are attached by thermocompression bonding with a heated chisel. In some instances, the beam-lead devices have leads sufficiently large to be attached by parallel-gap welding. A visual inspection followed by a quality-control lot-acceptance test is performed at this point.

The leads from the semiconductor devices to the network conductor pattern are attached by thermocompression ball bonding. The completed portions of the circuit are electrically tested and any defective devices are replaced by recycling the circuit through the assembly procedure. After satisfactorily meeting the electrical performance requirements, the circuit is visually checked and subjected to a quality-control lot-acceptance inspection.

The RF transistors are mounted on the circuit at a slightly lower substrate temperature than the previous alloying operations, using a gold-tin preform. The connections from the devices to the circuit pattern are made by thermocompression chisel bonding, using gold wire from 0.0003" to 0.0007" in diameter as the lead material. Any interconnecting wires or straps needed for circuit continuity are now bonded to complete the assembly process. The completed circuit is visually inspected followed by the specified sequence of dc and RF electrical testing. If more than one

circuit is to be mounted in the module package, the individual circuits are subjected to a stabilization bake before testing and a power burn-in after testing. The units are re-tested after power burn-in to verify the circuit performance.

The circuit(s) is assembled in the module package, tested electrically and stabilization baked for a specified period. The unit is then retested, sealed and tested for hermeticity. The module is given a power burn-in at maximum rated power input and temperature following by environmental testing, if required, and a final electrical test. The package is symbolized, visually inspected, and given a final quality-control lot-acceptance test.

It should be noted that the bake and burn-in temperatures noted on the flow chart are typical for microwave hybrid microcircuits. In many instances, the assembled modules are processed at somewhat lower temperatures, due to limitations imposed by the characteristics of the module components.

3.7.2.3 Package Leads - Microwave modules, in general, require that at least one set of external connections be made through a plug-in or screw-on coaxial-type connector. It is felt that the provisions for welding and/or soldering are not applicable to these types of external connections. The coaxial connectors should be manufactured to conform to the appropriate standards regarding materials, workmanship and performance (MIL-C-39012A).

3.7.3.1 "Carrier-Mounted" Chip Devices - It is felt that the use of directly mounted chip devices should be permitted where the use of special carriers, such as beryllia, is not required to enhance thermal conductivity or where special electrical evaluation is required prior to mounting the devices on circuits. The procedure of directly mounting the chips provides more effective use of the device's electrical characteristics at microwave

frequencies and reduces the circuit dimensions and complexity. Available data indicated that device reliability can be achieved through the use of: 1) adequate inspection criteria, 2) carefully monitored assembly operations in controlled atmospheres prior to hermetic sealing of the package, and 3) power burn-in requirements for individual module circuits as presently specified.

3.7.3.2.1 Plastic - There are innumerable varieties of plastic materials with a comparable range of compositions and characteristics. Because of the dependence of properties on suppliers compositions, age, curing conditions, adjacent materials, etc., the use of plastics, particularly organics, should be avoided whenever possible and when the use of such materials is mandatory they should be carefully controlled. It is felt that the use of a plastic (and organic material) must be justified by quantitative data from the manufacturer or other authoritative sources to verify the material's qualifications for a particular application. In the absence of such information, the properties of the plastic material should be checked to determine its suitability for the proposed useage. Information regarding the typical material characteristics and types of impurities which should be investigated has been taken from an article, "Resin Systems for Encapsulation of Microelectronic Packages", Solid State Technology, August 1970, Henry Hirsch. This article also describes methods and techniques for evaluating the physical and chemical properties of plastics which are being considered for electronic applications.

3.7.3.3 "Flip Chips" - The reference to "Beam-Leaded" Chip Devices has been eliminated from this section. Recent life tests of silicon beam-lead transistors and integrated circuits have shown that these units are superior to conventional silicon transistors and integrated circuits.¹ Independent reliability data from comparable tests at Texas Instruments has substantiated the information shown on the referenced graph. It is believed that beam-lead semi-conductor devices which have been properly processed and mounted will possess reliability equal to or better than conventional devices.

¹"Reliability of Beam Lead Sealed Junction Devices", 1969 Annual Symposium on Reliability, D.S. Peck

In addition, the wide leads provide the advantage of low lead inductance at microwave frequencies. The reduction in bonding operations simplifies the mechanical assembly.

3.7.4 Substrates - The choice of substrate materials for use in fabricating microwave hybrid microcircuits should be based on the following factors:

- 1) Dielectric Constant
- 2) Dielectric Loss
- 3) Surface Finish
- 4) Dimensional Tolerances
- 5) Composition (purity)
- 6) Magnetic Properties
- 7) Thermal Conductivity
- 8) Thermal Expansion
- 9) Uniformity
- 10) Electrical Conductivity
- 11) Mechanical Strength
- 12) Cost and Availability

Most of these factors involve considerations which are mutually incompatible and which require that some compromises be made in the selection of a suitable substrate material.

Dielectric Constant - High-purity alumina ceramic and sapphire (crystalline Al_2O_3) are considered to be the most satisfactory substrate materials for general microwave applications. The dielectric constant for Al_2O_3 of approximately 9.5 represents a compromise between quartz with a lower ϵ of 3.8 and rutile (TiO_2) with a higher value of approximately 100. The effect of a low value of dielectric constant is to increase the circuit dimensions (and cost) and to increase the amount of power radiated from the transmission lines. The effect of a high value

of dielectric constant is to increase the stray capacitance of inductors and to accentuate the detrimental effect of dimensional tolerances on circuit design and performance. A dielectric constant of about 10 has been found to give an optimum compromise for design purposes in the majority of cases. For circuits which use lumped components (usually 1 GHz or lower) the lower dielectric constant materials, such as quartz, are more suitable in this respect.

Dielectric Loss - The dielectric loss is determined by the material characteristics and purity. Quartz (fused silica), high alumina (99.5% + Al_2O_3) ceramics, sapphire and rutile (when considered on the basis of wave-length) have satisfactory loss characteristics for use as microwave microstrip substrate materials. Glass, glazed alumina ceramics and beryllia are poor microstrip substrate materials because of the relatively higher loss factor, i.e., approximately two orders of magnitude greater than those listed above.

Surface Finish - Surface finish has a significant effect on the loss for microstrip transmission lines and the effect increases with frequency. Tests have been made comparing ground and polished surfaces and as-fired and lapped surfaces. The results of these tests show that a finish of 10 microinches or better is satisfactory for fabricating high-Q (low-loss) microstrip lines, although a 2 to 4 microinch finish would show some measurable improvement particularly at higher frequencies.

A higher quality surface finish of one microinch or better is required for thin-film-capacitor substrates and the uniformity and reliability of thin-film resistors is considerably enhanced by the use of substrate materials of a comparable finish. The requirements of low microstrip-transmission-line loss and one-microinch surface finish for thin-film components can be satisfied by using selectively glazed, high-purity alumina ceramics or polished sapphire for substrate materials.

Dimensional Tolerances - High-purity alumina substrates having dimensions in the order of 2" by 2" by 0.020" thick, dimensional tolerances of +0.004"/inch camber, and a surface finish tolerances of ten microinches, or better, can be procured in production quantities at nominal cost. These tolerances are satisfactory for most microwave circuit applications. Closer tolerances can be obtained by grinding and polishing or special processing at a cost premium of about an order of magnitude higher. Materials such as sapphire and fused silica require grinding and polishing, and in addition, they have a higher intrinsic material cost. In general, the use of higher substrate costs can be justified only in high-density circuit packaging and/or where there is a need for close dimensional tolerances or a specific substrate material. The use of ferrite ceramic substrates is an example of the latter requirement.

Composition (Purity) - Microstrip substrates should have loss factors in the range of 10^{-4} at microwave frequencies. Materials which satisfy this requirement are 99.5%+ purity alumina ceramics, clear fused silica and sapphire.

Magnetic Properties - Ferrite ceramic materials are often used to construct phase shifters, circulators, filters, etc., for microwave systems. Non-magnetic ferrites (i.e., ferrites with a curie temperature much below room temperature) can be sintered to magnetic ferrites to form smooth "non-magnetic" substrates with magnetically active zones. The electrical discontinuities are low due to the similar nature of the materials and the ferrites can be machined and polished more easily than alumina to obtain low-loss transmission lines. The principal disadvantage of ferrites compared with alumina is the ten-times-lower thermal conductivity.

Thermal Conductivity - The thermal conductivity of the common substrate materials ranges from 0.003 for clear fused silica, to 0.088 for high-purity alumina and sapphire, to 0.55 for 99.5% beryllia. In general, high-purity alumina ceramics fulfill the requirements for microwave circuitry, while beryllia substrates are employed as carriers for microwave power transistors and similar applications.

Thermal Expansion - The thermal coefficient of expansion must be considered for metallization systems, component mounting, and mounting individual circuit substrates on carrier plates or packages. The thermal expansion coefficient for both beryllia and alumina in the high-purity form is about 6×10^{-6} . Metals which have approximately the same coefficient are chromium, iridium, molybdenum, niobium, silver, tantalum and vanadium.

Availability and Economics - Of the several materials which are used for microcircuit substrates, high-purity alumina and glass are available in the widest range of dimensions at a reasonable cost. High-quality quartz (fused silica), sapphire, beryllia, ferrites and high-resistivity silicon are limited in the range of dimensions available and/or are available only at a cost premium relative to the materials listed above. The geometry requirements, circuit performance aspects and the substrate cost, relative to that of the total circuit, must be evaluated in the course of specifying substrate materials for microwave hybrid microcircuits.

3.7.4.1 Surface Finish for Microwave Circuitry - The surface finish of a substrate must be less than 1 microinch, CLA, in order to fabricate thin-film capacitors. In addition, the uniformity of resistance elements is substantially improved by a better surface finish. The surface finish of as-fired high-purity alumina ceramics can be controlled to less than 10 microinches, CLA, which is satisfactory for most microwave transmission-line applications and resistor processing.

3.7.4.2 Surface Finish for Non-Microwave Thick-Film Circuitry - A substrate finish of 40 microinches, CLA, is satisfactory thick-film non-microwave circuit fabrication.

3.7.4.3 Dielectric Constant - The effective dielectric constant is one of the key factors involved in the design and fabrication of microwave microstrip transmission lines. It has been determined that the effective dielectric constant of high-purity alumina substrates varies between suppliers and even as much as 10% between batches from the same supplier. In order to fabricate microwave integrated circuits having reproducible

electrical performance, it is essential that the dielectric constant of the substrate material be carefully monitored and controlled.

3.7.4.4 Dielectric Loss - The loss factor ($\tan \delta$) of the dielectric substrate is one of the controlling factors in electrical performance of microstrip transmission lines and distributed circuit elements. Quartz (fused silica), high alumina (99.5%+) ceramics, sapphire, and rutile (when considered on a wave-length basis) have satisfactory loss characteristics for use as microwave microstrip substrate materials. It is necessary to specify maximum-loss-factor values and those listed are practical for commercially available substrate materials.

3.7.4.5 Thickness - The dielectric-substrate thickness is a determining factor for the characteristic impedance of a microstrip transmission line or the impedance value of a distributed circuit element. Substrates made to the tolerance specified are commercially available from several suppliers.

3.7.4.6 Purity - The purity of ceramics is the dominant factor in specifying the electrical and mechanical properties of ceramic material. Both alumina and beryllia ceramic substrates are available with 99.5%+ purity at a nominal cost.

3.7.5 Design and Processing Controls - The title and content of this section heading has been generalized to reflect the additional processes such as etching and plating used in fabricating film networks on dielectric substrates.

3.7.5.1 Circuit Element Spacing - The minimum design spacing requirements have been revised to accommodate the needs of microwave circuits. The tolerances now stated are well within practical values for the voltage listed. Measured breakdowns in air are greater than 300 volts for spacings of 0.0001"^{1,2} and the dielectric strength of 99.5% alumina substrate material is in the order

¹"Departure from Paschen's Law of Breakdown in Gases," Physical Review, January 15, 1955, W.S. Boyle and P. Kisliuk

²"Electrical Breakdown between Close Electrodes," Air Journal of Applied Physics, January 1959, L.H. Germer

of 500 volts/mil (manufacturers data sheet). Since the circuits are sealed in dry air or nitrogen, the specified minimum spacing of 0.0005" provides a substantial design safety factor.

3.7.5.2 Conductor Width - In some cases, circuit designs require the use of high-impedance transmission lines and holes. Since the characteristic impedance varies inversely with line width, it is necessary to use conductors as narrow as possible with reasonable circuit losses. Selectively plated gold conductors can be formed with a width tolerance of approximately ± 0.0001 " and, thus, a minimum conductor width of 0.001" is well within processing capability.

3.7.5.3.1 Segment Length - The acceptable resistor segment length has been reduced to 0.010" in order to produce low-value resistors with a minimum surface area. This dimension can be controlled to better than 0.001" and thus 10% tolerances can be held with no difficulty. The allowable power dissipation is also a factor in determining the minimum dimensions for resistor elements. The power dissipation properties of a resistor element depend on many factors such as the resistor material and thickness, the resistor coating material, the resistor configuration and the thermal properties of the substrate material.

3.7.5.4 Capacitors - Due to the fact that microwave circuits are designed to operate at relatively low impedance levels (i.e., less than 1 ohm to approximately 200 ohms), capacitive elements must have very low losses. For this reason, capacitor elements must use dielectric materials which have very low losses at microwave frequencies. In addition, the resistive losses must be held to a very low value. (Two structures which incorporated these desired features have been included in this section.) Tantalum pentoxide and silicon dioxide have excellent loss characteristics at microwave frequencies. The aluminum layer under the bottom capacitance electrode and the selectively plated gold top electrode and transmission lines provide a low resistive path for the RF current through the capacitor. A sectional view of a typical microwave capacitor structure is shown in Figure A-7-A, Appendix A.

3.7.6.1 Conductor Bonds - It is frequently desirable to use gold strap for inter or intraconnections within a microwave hybrid microcircuit in order to minimize the impedance discontinuities of the microwave transmission lines. The strap width is varied to match the substrate-conductor dimension. The results of pull tests of wedge (chisel) bonds made under various conditions indicate that extremely reliable bonds can be achieved with proper equipment parameter and satisfactory process controls. Comparable studies of thermo-compression ball bonds and parallel-gap welds of wire and strap material indicate that periodic monitoring of the operator-machine combination is necessary and sufficient for the production of highly reliable device and circuit connections. Recommended minimum pull-test values for monitoring wire and strap-bonding equipment are given in Table IV. These values have been determined by Texas Instruments quality control personnel - taking into consideration the ultimate breaking strength of the material. The pull-test minimum values for random sampling of production bonds are approximately one-half the quantities listed in the table.

3.7.6.2 Conductor Length - The table listing the maximum lengths of conductors used for interconnections has been expanded to include the smaller diameter wire used for bonding microwave transistors and diodes and the strap used for connecting microwave transmission lines.

3.10 Repair and Rework - The stringent performance requirements and complexity of many microwave circuits require that provisions be included in the manufacturing specifications for rework cycling. Microwave transistors and diodes often must be changed for proper impedance matching at specific power levels, since it is difficult to characterize these units completely prior to installation in the circuit. For tuning purposes, discrete chip capacitors must be changed out or taps must be movable on spiral inductors. By the use of proper rework procedures and definitive inspection and quality-control criteria, the circuit reliability can be maintained or enhanced while achieving the desired circuit performance.

6.1 Definitions of Terms - The list of definitions of terms has been revised for clarification and for expansion to include microwave applications.

APPENDIX A
RECOMMENDED DESIGN STANDARDS
FOR
CUSTOM MICROWAVE HYBRID MICROCIRCUITS

The information presented in Sections 20.1.3.1.1, 20.1.3.1.2.1, 20.1.3.2, 20.1.3.2.2, 20.2.1, 20.4.5, 20.7.1, 20.7.2, 20.9, 20.9.1, and 20.9.5 corresponds to accepted industry practice for producing microwave hybrid microcircuits and has not been altered.

20.1.1 Film Layout - The design of microwave circuits usually involves the use of spiral inductors, wavy transmission lines and/or mitred corners on microstrip beads. For these reasons, it is not practical to conform to parallel layouts.

20.1.2 Crossovers - It is desirable to use jumper straps of the proper width for circuit crossover in order to minimize the discontinuity effect for RF transmission lines.

20.1.3.1 Thin Film - The photoplatting method for pattern delineation has been added to this section. This process is used to form the relatively thick conductor patterns which minimize transmission losses with greater accuracy and it is also more economical than conventional photo-etching methods.

20.1.3.1.2 Additive - More accurate pattern definition of complex metallization patterns can be achieved by using nickel-plated spring-steel masks. Small castellated magnets are placed on the opposite side of the substrate to hold the mask against the substrate during the vacuum-deposition sequence.

20.1.3.1.3 Selective Plating - As stated previously, this process is added to form accurately defined, relatively thick conductor lines at minimum cost.

20.1.3.2.1 Screen Printing - It is necessary to control line widths in microwave circuits to accuracies less than 0.001". Screening and firing techniques do not normally achieve these tolerances and a photo-etching operation can be included to give the desired dimensional accuracy.

20.2.2 Holes - The layout of microwave circuits requires that terminations and ground connections be located at discrete points on the circuit layout. Particularly, at frequencies of 2 GHz and above, it is necessary to have plated-through ground connections at the proper position on the circuit layout. No mechanical problems have been encountered in fabricating circuit networks with drilled holes when the clearance dimensions noted have been used.

20.3 Conductor Requirements

20.3.1 Material - The losses in microwave conductors depend on the resistivity of the material provided the conductor is more than two or three skin depths thick. In addition, it is very desirable to use a material, at least on the surface, which does not corrode and which provides an easily bondable material for welding and thermocompression bonding. Magnetic materials increase the circuit losses when used as a layer of the conductor pattern.

20.3.2 Conductor Length - The length of microwave transmission lines used as distributed circuit elements is determined by the electrical requirements. The width, thickness and materials must be optimized to keep circuit losses to a minimum. Experimental evidence shows that mitre or radius bends do not contribute as much to circuit loss as square bends when it is necessary to fold lines for space requirements or to fabricate square coils.

20.3.3 Conductor Thickness - In order to maintain RF conductor losses, it is necessary to fabricate conductors with thicknesses of two to three skin depths based on the material(s) and operating frequency. The maximum resistivity for dc conductors has been reduced to 0.01 ohms/square since this value can be achieved easily and space requirements normally dictate the use of relatively narrow bias lines for microwave microcircuits.

20.4 Resistor Requirements

20.4.1 Materials

20.4.2 Resistor Geometry - The geometry for microwave resistors should be simple and rectangular in order to control the effects of end-to-end capacitance and inductance. The size should be as small as possible, consistent with power dissipation requirements, in order to approach the lumped-component characteristics of a resistor element.

20.4.3 Resistor Corners - In theory, the use of conductor films over the ends of zig-zag resistor patterns simplifies the design and reduces "current crowding" at the corners. However, the effect of multiple "contact resistance" points between the metal-to-metal interfaces is also a problem which must be considered, particularly for precise resistor elements. It is not practical to have conductor material overlaying the resistor material (usually tantalum) when trimming by electrolytic anodization is employed. Pinholes in the photoresist mask allow the electrolyte to be "shorted" to the conductor pattern.

20.4.4 Resistor Tolerance and Adjustments - The trimming process should not reduce the resistor cross section more than 40% in order to control the degrading effect of hot spots in the resistor material.

20.5 Capacitor Requirements

20.5.1 Deposited Capacitors - The revision to this section is self-explanatory. The example shown in the illustration has five layers. Aluminum is placed under the bottom tantalum layer to reduce series resistance and the chromium is placed between the tantalum pentoxide dielectric and the gold top plate to improve the adherence between the two materials.

20.5.1.1 Testing - Film components should be electrically tested after fabrication to check parameter conformance and improve reliability. Test results indicate that leakage current measurements are essential to assure reliable components..

20.5.2 Materials - The dielectric loss of materials varies substantially in the microwave region. In particular, the high-K dielectrics tend to be more lossy at higher frequencies.

20.5.3 Discrete Capacitors - Many types of dielectrics are used in chip capacitors and the comments of 20.5.2 above apply equally well here.

20.6 Inductors - The use of inductors at microwave frequencies varies substantially from the low-frequency applications. The numerical design data presented has been taken from measurements at Texas Instruments and other companies. In general, the material is self-explanatory, but additional background material and verification of design factors can be obtained from the narrative reports and accompanying bibliography.

20.7.1 Plastic (Organic) Adhesive - The list of items to be evaluated before the use of a plastic material is specified and included in order to emphasize the need for control of these materials. In many instances, the detrimental effect of the constituents of the plastic or the degradation of the material characteristics with time and temperature preclude its use in the fabrication of reliable circuit modules.

20.8 Mounting Pads - It is believed that MSFC Specification 85M03926 contained a typographical error and that the chip dimension should be 0.007". The illustration appears to confirm this assumption. In addition, our experience has been that a minimum of 0.005" pad space greater than the chip dimension is necessary to provide a suitable mounting pad area.

20.9 Interconnections

20.9.2 The use of gold strap of the proper width is desirable in making connections from the chip carrier to the network substrate or package lead in order to reduce the lead inductance and/or minimize the electrical discontinuity. Multiple wire bonds from the semiconductor chip to the carrier or network substrate tend to achieve a similar result.

20.9.4 The phraseology has been changed to provide a more general concept.

20.9.6 Intermediate Bonding Pads - In some instances, the microwave circuit performance may be substantially improved by bonding directly between chips. Procedures are available for chisel (wedge) bonding between chips or ball bonding through the use of auxiliary balls which can provide a reliable fabrication process.

20.10 Heat-Dissipation and Transfer Problems - In addition to the usual heat-dissipation problems, microwave semiconductor devices have a specific problem related to the device geometry and the operational frequency. Most low-frequency transistor chips have a small number of active areas. However, microwave transistors may have up to several hundred individual active device areas. Non-uniformity in process conditions may result in a device which has locally concentrated, high-power dissipation areas. Also, current crowding can occur due to the RF circuit aspects of the device. Therefore, it is necessary to use conservative design approaches with respect to operating junction temperature and to check the peak junction temperatures with an IR radiometer in order to assure the reliability of the circuit module.

APPENDIX B
QUALITY STANDARDS
FOR
CUSTOM MICROWAVE HYBRID MICROCIRCUITS

The information presented in Sections 20.1.2, 20.1.3.2, 20.1.4.1, 20.1.6.2, 20.1.6.4 to 20.1.6.6, 20.1.7.2 to 20.1.7.5, 20.2 to 20.6 represents good practice in establishing quality standards for microwave hybrid microcircuits. The gross leak test described in Section 20.2.1 is preferred over that referenced in Section 20.2.2.

20 Screening - The notation in Table B-1 has been changed to conform to the latest revision of MIL-STD-883.

20.1 Visual Inspection, -Pre-Seal - This paragraph has been corrected to correspond to the latest revision of MIL-STD-883, Notice 2, dated 20 November 1969.

20.1.1.1 The reference to a binocular microscope has been changed in a later edition of MIL-STD-883 to read "monocular, binocular, or stereo microscope". Consequently, this exception has been deleted.

20.1.1.2 The paragraph reference has been corrected and is now listed as paragraph 20.1.1.1. Maximum allowable dimensions for attached foreign material has been added and the definition for conductive material has been reinstated accordingly.

20.1.1.3 The referenced paragraph has been deleted from MIL-STD-883. The definition of a scratch is given in this paragraph and is based on paragraph 3.2.1.1. (a) and Figure 2010-7, MIL-STD-883.

20.1.1.4 Paragraph 3.2.7.2 refers to voids on capacitors and crossovers. There is no detrimental effect from a metallization void on a capacitor or crossover provided the circuit meets electrical specifications and paragraph 3.2.1.2

is not violated.

20.1.1.5 Paragraph 3.2.7.4 refers to voids and scratches on resistors. This criteria is covered in paragraph 20.1.5.1 of MSFC Specification 85M03926.

20.1.3.1 Eutectic Mount - This section has been changed to require 75-percent eutectic around die. This corresponds to paragraph 3.1.6.2, MIL-STD-883, and is the most stringent requirement corresponding to Test Condition A. It is felt that the revision indicated will not measurably degrade the product quality and will provide a highly reliable circuit.

20.1.3.3 Solder Mount - This section has been changed for the same reason given above. Wording has been added to cover the case of slug capacitors with metallized terminations.

20.1.4.2 Spacing Between Metallization and Substrate Edge - In order to reduce electrical discontinuities between adjacent circuits in a microwave hybrid microcircuit module, it is necessary to continue transmission lines as close to the substrate edge as possible. It has been found to be quite satisfactory to maintain a minimum spacing of 0.001" from the metallization edge to the substrate edge for quality and reliability purposes. The essential criteria is that the metal not extend beyond the edge of the circuit substrate, particularly if the units are to be separated by sawing or scribing, since this could lead to metallization peeling.

20.1.6.1 Placement - The paragraph has been revised to correspond to what is considered to be good practice for high-reliability circuits. Reference is made to paragraphs 3.1.4.2 (b), 3.1.4.3 (c) and Figure 2010-6, Test Condition A, MIL-STD-883.

20.1.6.1 Wire Stress Bond - The work "perpendicular" has been changed to "vertical" to allow a slight variation from a 90° angle.

20.1.7.1 Width - This paragraph has been revised so as not to preclude "Unitip" welding, which uses tips with fixed design spacing. This equipment utilizes an adjustable power supply and weldhead pressure and produces excellent bonds.

20.1.7.4 In many instances, the weld tip is not as wide as the strap material and multiple welds must be made to complete the bond.

20.1.7.5 Refer to 20.1.7.4

20.1.7.6 Setdown - Good practice in parallel-gap welding indicates that a round wire should be reduced approximately 50% in section for a reliable weld. This section has been altered to reflect this criteria.

20.1.7.7 Strap Loop - It is necessary to place a loop in a welded strap interconnection in order to compensate for differences in thermal coefficient of expansion of the various component substrate and lead materials.

APPENDIX D
THIN-FILM CAPACITOR BURN-IN DATA

D-1

DATA SHEET

BEAM-LEAD TANTALUM CAPACITORS

TI MDO-823 150, L

☒ - FAILED WITHIN FIRST 1000 HRS $I_L > 200 \text{ NA}$
☒ - FAILED DURING 2ND 1000 HRS

DATE

PAGE OF

1/2

TAKEN BY

823-1

823-1- LEAKAGE @ 30V IN NA.

823-1- LEAKAGE @ 30V IN NA.

#	INITIAL	1000HR	2000HR			#	INITIAL	1000HR	2000HR
<input checked="" type="checkbox"/> 1	15.6	210 μA	2.4 μA			26	24	4	1.9
2	12	14	5.1			27	17	4	2.0
3	4.8	3	1.2			28	12	10	2.2
4	7.6	10	4.2			29	66	17	3.3
5	15	18	370			30	10	7	3.5
6	11	4	1.9			31	23	3	1.6
7	5.6	6.5	3.3			32	110	3.5	1.6
8	14	9	4.8			33	12	3	320
9	14	12	5.4			34	13	7.5	4.2
10	16	17.5	6.4			<input checked="" type="checkbox"/> 35	13	800 μA	4.1
11	44	3.5	1.5			36	17	17	5.6
12	13	14	1.7			37	14	3	1.7
<input checked="" type="checkbox"/> 13	16	40 μA	320			38	26	5	5.3
14	20	7.0	4.2			39	10	120	2.7
15	14	52	6.6			40	24	3.5	2.0
16	7.6	4	0.9			41	27	2.5	1.5
17	13	3	4.4			42	12	11	5.2
18	13	3.5	10			43	13	14	6.0
19	28	.05	1.9			44	14	17	5.6
20	14	51	1.6			45	85	47	20.
21	23	17	1.7			46	43	30	1.3
22	12	28	48			<input checked="" type="checkbox"/> 47	11	10	1200
23	18	30	2.0			48	11	4.5	1.9
24	15	17	2.0			49	14	3	2.5
<input checked="" type="checkbox"/> 25	51	SHORTED	SHORTED			50	14	3	1.5

DATA SHEET

BEAM-LEAD TANTALUM CAPACITORS

TI - MUB 923 150pf

Δ - FAILED WITHIN FIRST 1000 - R $I_L > 200NA$
 \boxtimes - FAILURE DURING 2ND 1000 - R

DATE	PAGE OF
TAKEN BY	2

823-2

823-2 LEAKAGE @ 30 V IN NA.

823-2 LEAKAGE @ 30 V IN NA

#	INITIAL	1000 HR	2000 HR		#	INITIAL	1000 HR	2000 HR
Δ 1	10	SHORTED	SHORTED		26	11	250NA	1.0
2	13	10.	HANDLING		Δ 27	16	2.1	6.0
3	8.6	5	2.5		28	27	2	1.4
4	11	10	4.5		29	13	3.0	1.5
5	16	11	4.8		30	14	3.6	1.2
6	11	4.5	2.1		31	11	11	4.5
7	17	18	6.2		Δ 32	27	540NA	HANDLING
8	11	10	10.0		33	32	2.0	1.0
9	18	16	12.0		34	12	1.5	.7
10	14	3.5	1.1		35	34	2.0	1.2
11	17	2.0	1.1		36	11	1.5	.8
12	11	15	6.2		37	25	2.0	1.0
\boxtimes 13	300		500		38	26	2.0	1.1
14	17	2	1.0		39	29	6.5	3.6
15	14	10	4.8		40	32	2.5	1.1
16	7.2	2.5	1.4		41	13	2.0	.5
17	10	7.0	3.2		42	84	2.0	1.0
18	11	7.0	3.4		43	28	2.0	1.1
19	14	2.5	1.3		44	32	2.5	1.2
20	13	2.0	1.4		45	11	15.1	5.4
21	9.1	4.0	3.2		46	6.6	4.	2.0
22	13	2.0	1.5		47	9.6	11.0	4.5
23	11	2.0	1.3		48	16	2.0	7.1
24	8.4	4.0	2.5		49	12	1.0	6.8
Δ 25	8.4	—	230		50	14	13	6.6

DATA SHEET

BEAM-LEAD DEPOSITED SiO_2 CAPACITORS
 TI MDO-830

DATE

PAGE OF

1/2

TAKEN BY

830-1 LEAKAGE @ 30V < 8.4 nA

830-1 LEAKAGE @ 30V < 8.4 nA

#	INITIAL	1000HR	2000HR		#	INITIAL	1000HR	2000HR
1	< 8.2 nA	→			26	< 8.2 nA	→	
2					27			
3					28			
4					29			
5					30			
6					31			
7					32			
8					33			
9					34			
10					35			
11					36			
12					37			
13					38			
14					39			
15					40			✓
16					41			22 nA
17			↓		42			< 8.2 nA
18			Broken		43			
19			< 8.2 nA		44			
20					45			
21					46			
22					47			
23					48			
24					49			
25	↓	↓	↓		50	↓	↓	↓

DATA SHEET

BEAM LEAD DEPOSITED SiO_2 Capacitors

TI MDG-830

DATE

PAGE OF

2 | 2

TAKEN BY

830-2 LEAKAGE @ 30V 22.2NA

830-2 LEAKAGE @ 30V 22.2NA

#	INITIAL	1000HR	2000HR		#	INITIAL	1000HR	2000HR
1	22.2NA	→			26	22.2NA	→	
2			↓		27			
3			HANDLING		28			
4			HANDLING		29			
5			22.2NA		30			
6					31			
7					32			
8					33			
9					34			
10					35			
11					36			
12					37			
13					38			
14					39			
15					40			
16					41			
17					42			
18					43			
19					44			
20					45			
21					46			
22					47			↓
23					48			150NA
24					49			22.2NA
25	↓	↓	↓		50	↓	↓	↓